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OKLAHOMA STATE UNIV STILLWATER ELECTRONICS LAB
TRADAT MICROCOMPUTER BASED TRAJECTORY SYSTEM, (U)

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1. Slant range to better than $\pm .05$ KM RMS, using a PCM ranging system in conjunction with the vehicle telemetry system.
2. A serial PCM trajectory data code (for tape recording) containing: (a) Time, (b) Status indicators, (c) Raw azimuth, elevation, and slant range data.
3. A microcomputer printout containing: (a) Time, (b) Status indicators, (c) Computed ellipsoidal Earth coordinate data (Mean sea level altitude, ground range, distance North, and distance East or mean sea level altitude, vehicle latitude, and vehicle longitude), (d) Azimuth, elevation, and slant range referenced to one of three selectable data origin sites.

This report contains an electrical and physical description of the Tradat V system, set-up and operation procedures, description of an optional command through ranging system, a microcomputer software description and equation derivation section, discussion of Tradat V mission results, and possible future development activities. The Tradat V system consists of a time code generator, ranging transmitter, line printer, and the Tradat V console plus the appropriate airborne system. Tradat V may be used with FM/FM or PCM telemetry system.

SUMMARY.

Tradat V is a lightweight, relatively inexpensive trajectory data system which was designed to be used with a portable autotrack antenna system. The combined Tradat V/Tracker system provides trajectory data for vehicles such as sounding rockets or balloons which are launched at remote launch sites where there are no fixed site radar sets. The tracker provides telemetry reception and the azimuth and elevation angles to the vehicle and the Tradat V system provides the following:

1. Slant range to better than $\pm .05$ KM RMS, using a PCM ranging system in conjunction with the vehicle telemetry system.
2. A serial PCM trajectory data code (for tape recording) containing: (a) Time, (b) Status indicators, (c) Raw azimuth, elevation, and slant range data.
3. A microcomputer printout containing: (a) Time, (b) Status indicators, (c) Computed ellipsoidal Earth coordinate data (Mean sea level altitude, ground range, distance North, and distance East or mean sea level altitude, vehicle latitude, and vehicle longitude.), (d) Azimuth, elevation, and slant range referenced to one of three selectable data origin sites.

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LIST OF CONTRIBUTORS

The following staff members (listed alphabetically) from the Oklahoma State University, Electronics Laboratory (Division of Engineering, Technology, and Architecture) have contributed to the work described in this report:

Richard F. Buck	William A. Holloway
Joseph M. Cooper	Leslie D. Hoy
Doyle K. Craft	Martha M. Luckey
Donald G. Dale	L. Orion Schmitt
Daniel C. Easley	Leonard J. Skach
Robert M. Fike	Rosalee I. Stafford
Tom B. Gwin	Jackie W. Spears
Claude M. Gwinn	Jerry R. Waughtal
Darrell L. Haston	Joe B. Zinn

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1.0 INTRODUCTION

The Oklahoma State University (OSU) Electronics Laboratory has developed a microcomputer based trajectory determination system called Tradat V (short for Trajectory Data). The Tradat V system (Figures 1 and 2) is used in conjunction with an automatic tracking antenna system such as the OSU developed Tratel (References 1 and 2) or Minitracker (Reference 3) system. The automatic tracking antenna provides the Azimuth and Elevation angles to the vehicle. Tradat V provides the following:

1. Slant range in Km using a PCM ranging system.
2. A serial PCM trajectory code (for tape recording) containing:
 - a. Time
 - b. Status indicators
 - c. Raw spherical coordinate data (Azimuth, Elevation, and Slant Range)
3. A microcomputer printout containing:
 - a. Time
 - b. Status indicators
 - c. Computed ellipsoidal Earth coordinate data (Mean sea level altitude, ground range, distance North, and distance East or mean sea level altitude, vehicle latitude, and vehicle longitude.)
 - d. Spherical coordinate data referenced to one of three selectable data origin sites (Tracker site, site 1, or site 2.)

The Tradat V system was designed to be a lightweight, relatively inexpensive means of providing trajectory data for vehicles such as sounding rockets or balloons which are launched at remote launch sites where radar sets are not readily available. Tradat V is the latest in a series of trajectory system developments at OSU which were begun more than 15 years ago.

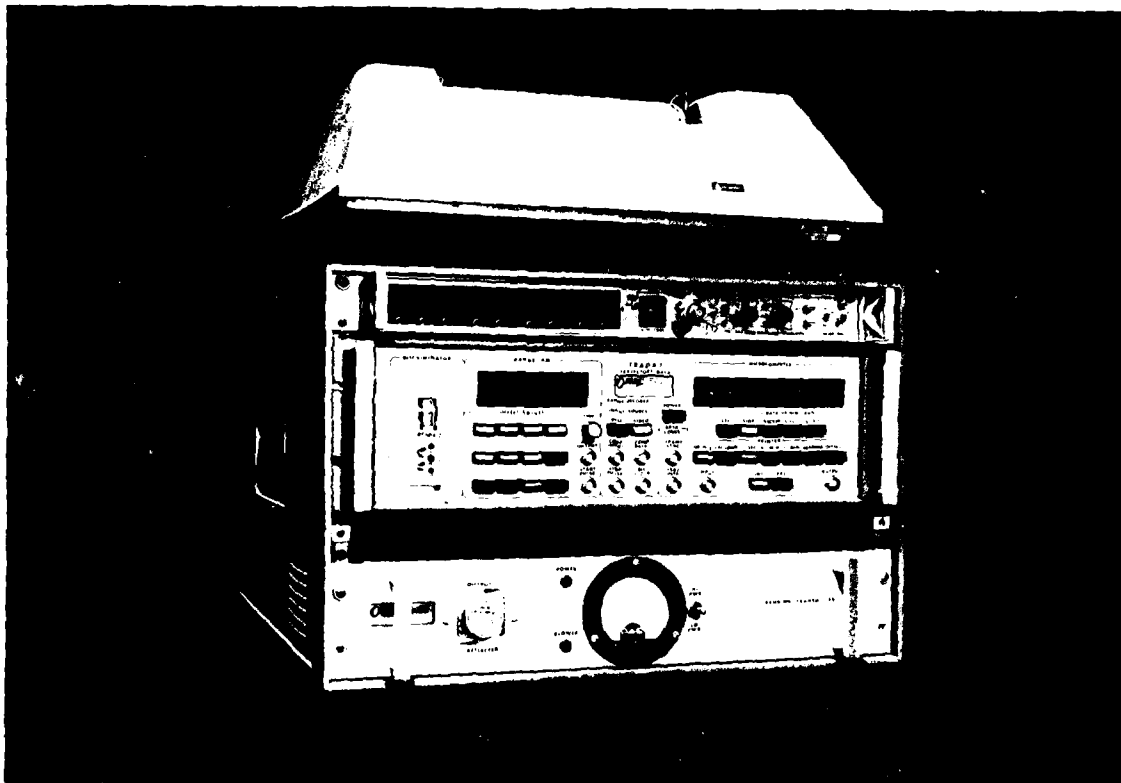


Figure 1. Tradat V System

2.0 TRAJECTORY SYSTEM

The Tradat V console may be thought of as two major functional systems as follows:

1. Trajectory System
 - a. Ranging System - Provides BCD range in Km.
 - b. Trajectory Data Coder - Provides serial PCM code of trajectory data for recording.
2. Microcomputer System - Provides a real-time or post-flight printout of computed trajectory data.

2.1 Electrical Description

2.1.1 Theory of Operation

Deriving the range involves the generation of a crystal-controlled 16-bit PCM code which is synchronized with the start pulse to the time interval counter. (Refer to Figures 1 and 2 for a photograph and block diagram of the Tradat V system). This code modulates a ranging transmitter which transmits the code to an airborne receiver. In FM/FM airborne systems the detected code from the receiver is used to modulate an IRIG channel 18 (70 KHz) subcarrier oscillator (SCO). This subcarrier is mixed with the data-bearing subcarriers and used to modulate the airborne transmitter. In PCM airborne systems the detected code from the receiver is filtered by a lowpass filter and mixed with the PCM telemetry data. The mixed ranging PCM code and telemetry PCM code is used to modulate the airborne transmitter. (For best ranging accuracy Tradat should be used only with biphasic PCM telemetry codes with bit rates greater than 200 KBPS.) The RF telemetry signal is received by a tracker and the receiver video output is cabled into Tradat where the ranging code is retrieved from the telemetry data by a channel 18 discriminator (when used with FM/FM systems) or by a lowpass filter (when used with PCM systems). The retrieved PCM ranging code is stabilized and reshaped in the bit synchronizer which also produces a stable bit clock. With a S/N of 20 db the bit sync can provide a code jitter of less than $\pm .050$ Km RMS. The received ranging code is decoded to produce a stop pulse to the interval counter. The interval counter averages ten start-stop pulses at each tenth of a second and provides a front panel range readout in kilometers to the nearest .010 kilometer.

The Tradat V chassis also contains a trajectory data coder which converts

the parallel BCD time, Azimuth (Az), Elevation (El), range and status indicator bits to a 1 Kbps biphase-level PCM code. The microcomputer in the Tradat V chassis computes ellipsoidal Earth coordinate data from the raw spherical coordinate data.

2.1.2 Ranging Code Generator and Sync Detector Card (OSU Drawing C95GE02)

The ranging code generator (Figure 3) produces the start pulse and the up-link PCM ranging code. A stable 4 MHz crystal oscillator is counted down to 1 MHz in IC 123 and entered into a 12-bit binary bit counter (IC103). The bit counter provides the 3906.25 Hz bit clock to the frame counter, and is inverted by IC111D to provide an inverted clock to the frame sync generator and to the optional external command system. The frame sync generator uses a shift register (IC113) to produce the NRZ-L serial PCM frame sync code and then uses IC111A to convert the code to Biphase-Level. The frame counter consists of a minor frame counter (IC109) and a major frame counter (IC110A, 102, and 112A). There are four 16-bit minor frames per major frame with a 7-bit minor frame sync, 1011000(1). The bit in parentheses is the major frame indicator and indicates a "1" every fourth minor frame. The last 8 bits of each minor frame are normally all "zeros" unless the command option is added, and then the last 8 bits of the four minor frames may consist of command data. The minor frame sync from the frame counter is used to provide a parallel enter to the shift register, thus restarting the cycle.

The minor frame sync also resets the bit counter to synchronize the start pulse with the PCM code. There is a start pulse associated with each minor frame such that a range of 613.98 Km (4.096 msec) may be reached with no ambiguity. The start pulse may be delayed to any point in the minor frame by selecting via front panel pushbutton switches either the inverted (\bar{Q}) or non-inverted (Q) outputs of the 12-bit binary bit counter as the input of a 12 input AND gate (IC106 and IC107). The bit counter outputs are inverted by IC104 and IC105. A fine delay adjustment may be made by varying the pulse width of a one-shot multivibrator (IC108A) following the AND gate. The interval counter is started by the trailing edge of this one-shot output. This delay technique is necessary to allow the range to be initialized for loop delay variations inherent in different telemetry system set-ups.

Alternate major frames of the PCM ranging code are inverted after two minor

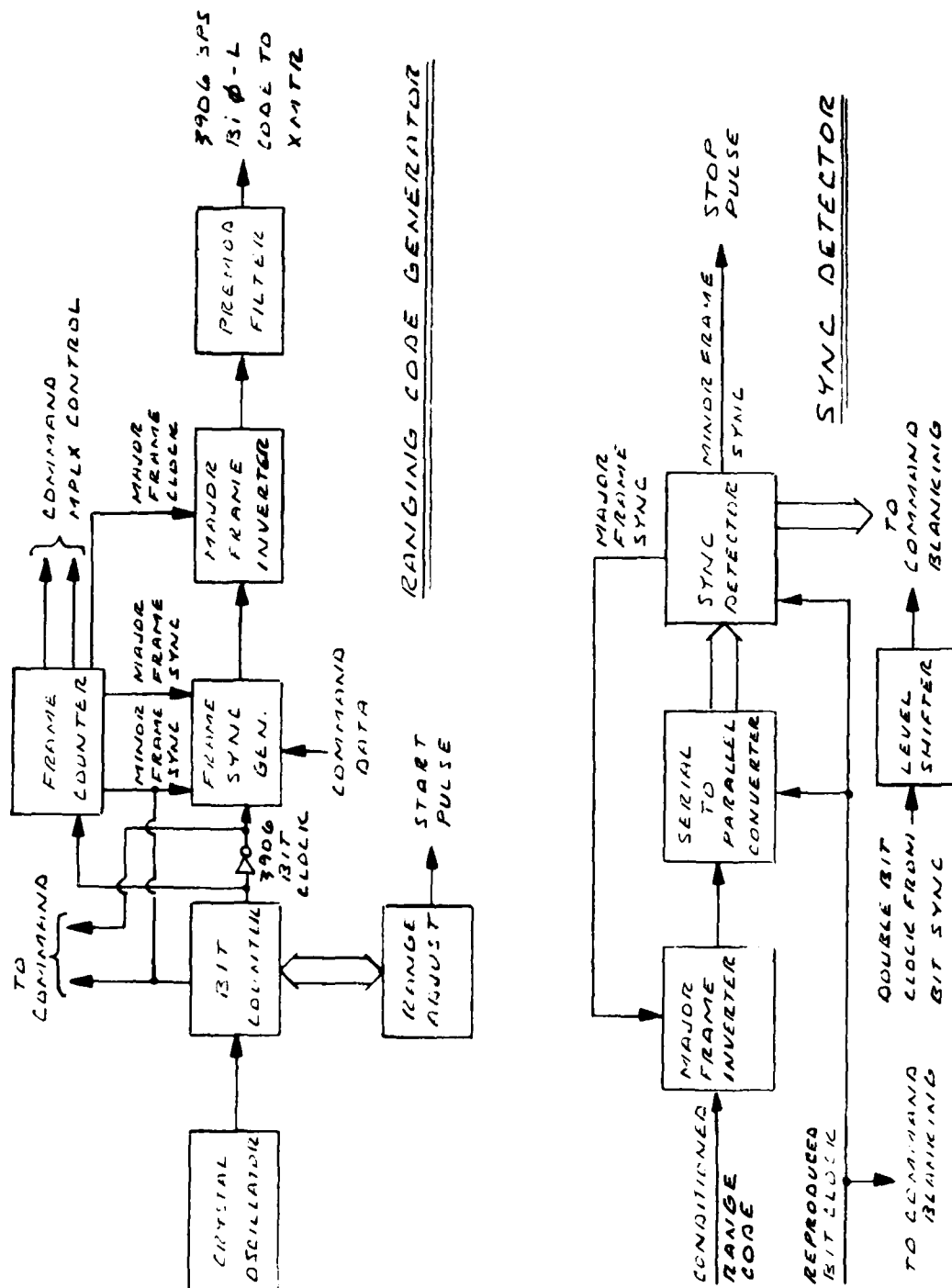


Figure 3. Ranging Code Generator and Sync Detector Block Diagram

frames by IC111B so that the frame sync detector is polarity independent and also to reduce range variations when the command option is used. The PCM code is then filtered in a 5-pole lowpass, premodulation filter (IC114) before it is used to modulate the uplink ranging transmitter.

The PCM ranging code is received and retransmitted in the airborne package as described in the previous section. Front panel pushbutton switches select either the receiver video for PCM telemetry systems or the discriminator output for FM/FM telemetry systems. The selected signal is fed into the Bit Sync Card where it is filtered and conditioned. A stable bit clock is also reproduced by the Bit Sync Card.

The conditioned range code and reproduced bit clock are fed to the Sync Detector (Figure 3) part of the Ranging Code Generator and Sync Detector Card. The inverted major frame of the conditioned data is reinverted by IC111C and IC112B to produce all non-inverted data. The serial PCM frame sync code is converted to parallel by IC118 and IC119 and fed into the sync detector. IC118 functions as a delay circuit. The minor frame sync is detected by IC101, IC120, IC117, and IC121A. The minor frame sync is used as the stop pulse to the interval counter. The major frame sync is detected by using the minor frame sync and the major frame indicator bit in IC110B, IC121B, and IC121C. The major frame sync is used in the major frame inverter to provide all non-inverted data. The sync detector also provides command blanking to the optional command console.

2.1.3 Bit Sync Card (OSU Drawing C95GE06)

The range code input to the Bit Sync Card (Figure 4) is selected from either the receiver "VIDEO" in PCM telemetry systems or from the discriminator ("DISC") output in FM/FM telemetry systems by means of front panel pushbutton switches. The range code is filtered in a custom designed 5-pole lowpass filter (IC602) and then conditioned by IC603 and IC604A to provide a square wave input to the sync detector on the Ranging Code Generator and Sync Detector card. The bit clock is reproduced by using IC604B to produce positive pulses at each code transition and using these pulses to drive a one-shot clock (IC605A). Another one-shot clock (IC605B) is used to make the clock symmetrical. This reproduced clock is used to drive a phaselock loop (PLL, IC607) which produces a stabilized bit clock. A two stage active loop filter (IC606) is utilized to provide optimum lock characteristics. A 1 MHz voltage-controlled crystal oscillator (VCXO) was used to provide stability and a narrow bandwidth.

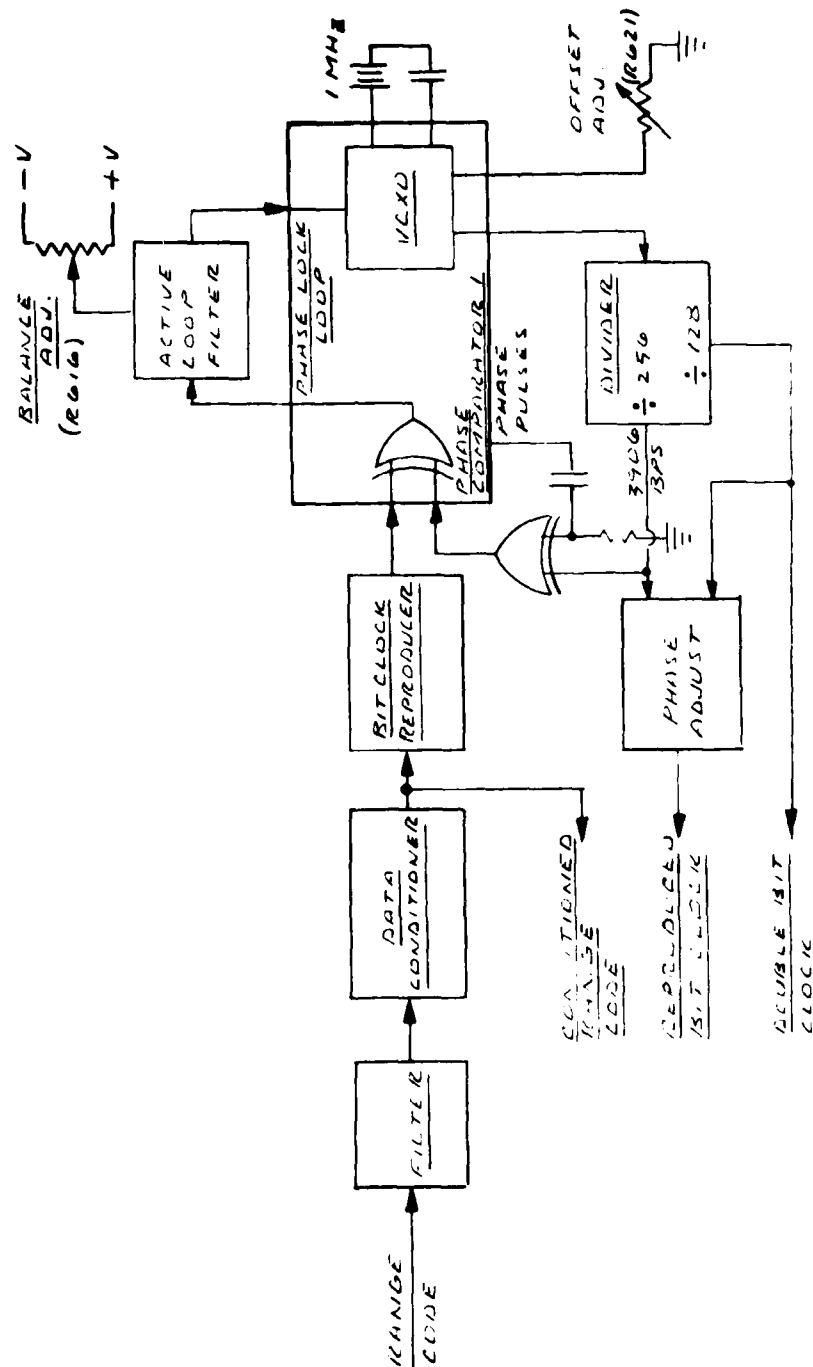


Figure 4. Bit Synchronizer Block Diagram

A rocket with a velocity of 2 Km/sec gives a bit clock slew rate of 13.3 microseconds/second. The VCXO bandwidth is set greater than ± 50 Hz to provide a slew rate greater than 50 microseconds/second. This is at least 3.75 times faster than the slew rate caused by the rocket velocity. The PLL slew rate allows a fast lock and accurate loop tracking. The PLL lock rate allows a maximum acquisition time of less than 2.5 seconds to lock on a stationary target. The VCXO output is divided down to 3906.25 Hz in IC608 and fed into one input of an exclusive "OR" gate (IC601B), with differentiated PLL phase pulses fed into the other input. This gate output then enters the PLL phase comparator where it is compared with the reproduced bit clock to provide the correction voltage through the loop filter to the VCXO. The 3906 BPS divider output is adjusted 270° in phase using IC604C and IC604D in order to have the proper phase relationship with the conditioned data. The conditioned range code and reproduced bit clock and double bit clock are fed into the sync detector part of the Ranging Code Generator and Sync Detector Card.

The phaselock loop is adjusted so that the free running VCXO frequency matches the range code generator's crystal oscillator. The loop bandwidth is adjusted to at least ± 50 Hz and not more than ± 70 Hz. The adjustment involves monitoring the correction voltage at pin 9 of IC607 and the VCXO frequency at pin 4 of IC607 and adjusting potentiometers R616 and R621 at the top of the wire-wrap card. The adjustments are made as follows:

1. Measure the frequency (F_G) of the crystal oscillator on the Ranging Code Generator and Sync Detector Card at pin 10 of IC103.

($F_G = 1,000,000$ Hz nominal)

2. Adjust R616 until the correction voltage equals +12v ($V_C = +12v$).

3. Adjust R621 until the VCXO frequency (F_X) is 50 Hz higher than F_G

($F_{XH} = F_G + 50$).

4. Adjust R616 until $V_C = 0_v$ nominal.

5. Measure F_X ($F_X = F_{XL}$).

6. Calculate the loop bandwidth (F_{BW}) and divide by two.

$$F_{BW}/2 = (F_{XH} - F_{XL})/2$$

7. Adjust R616 until $V_L = +12v$.

8. Adjust R621 until $F_{XH} = F_G + F_{BW}/2$ (or the maximum to which it can be adjusted, but never more than $F_G + 70$).

9. Adjust R616 until $V_C = 0v$ nominal.

10. Measure F_X ($F_X = F_{XL}$) to verify that $50 \text{ Hz} < (F_G - F_{XL}) < 70 \text{ Hz}$.
 11. If $F_{BW} < \pm 50 \text{ Hz}$, reduce the value of the range adjust resistor (R619) to increase the loop bandwidth and repeat steps 2 through 10.
 12. Adjust R613 until $F_X = F_G$.
- The last adjustment centers the VCXO frequency in the loop bandwidth.

2.1.4 Time Interval Counter Card (OSU Drawing C95GE05)

The Time Interval Counter Card averages ten range intervals to provide an averaged BCD range to the front panel display and to the Trajectory Data Coder. A range interval is defined as the time interval between a start pulse (corresponding to the time the PCM ranging code frame sync is transmitted up to the airborne vehicle) and a stop pulse (corresponding to the time the PCM ranging code frame sync is detected in the ground system after retransmission from the airborne vehicle). A range period is the time interval (4.096 msec) between one start pulse and the next start pulse. The averaging period consists of ten range periods centered within a few milliseconds of the 10 pps "on" time from the time code generator so that the range entered on the trajectory data code has a direct time correlation. The averaging period starts 20 msec before the 10 pps "on" time and ends approximately 20 msec after the 10 pps "on" time. Refer to Figures 5 and 6 for the Interval Counter Card block diagram and waveforms. (Numbers in parentheses which follow refer to the waveforms numbered in Figures 5 and 6.)

The averaging period starting point (2) is set by a delay circuit (IC401 and IC402) using the 10 pps and 1000 pps clocks. These clocks originate in the time code generator but are reshaped in the Trajectory Data Coder Card. This 80 msec delayed pulse allows the averaging period to start 20 msec before the 10 pps "on" time and is conditioned to provide an inverted (\bar{Q}) and non-inverted (Q) pulse. After the averaging period reset by IC403 (2) opens the averaging period gate (IC408 and IC407A), ten range intervals are counted through it to provide an averaging period (5) of 40.96 msec. The averaging period varies in length up to $\pm 4.096 \text{ msec}$ continuously with variations in the ten range interval lengths and their starting point in the averaging period. This variation amounts to a maximum possible range error of less than .001 Km for a rocket acceleration of 35 G's ($.344 \text{ Km/sec}^2$). The averaging period (5) opens the start pulse gate (IC407B) and allows ten start pulses to set the range interval gate (IC405) which is reset by stop pulses to form the range intervals

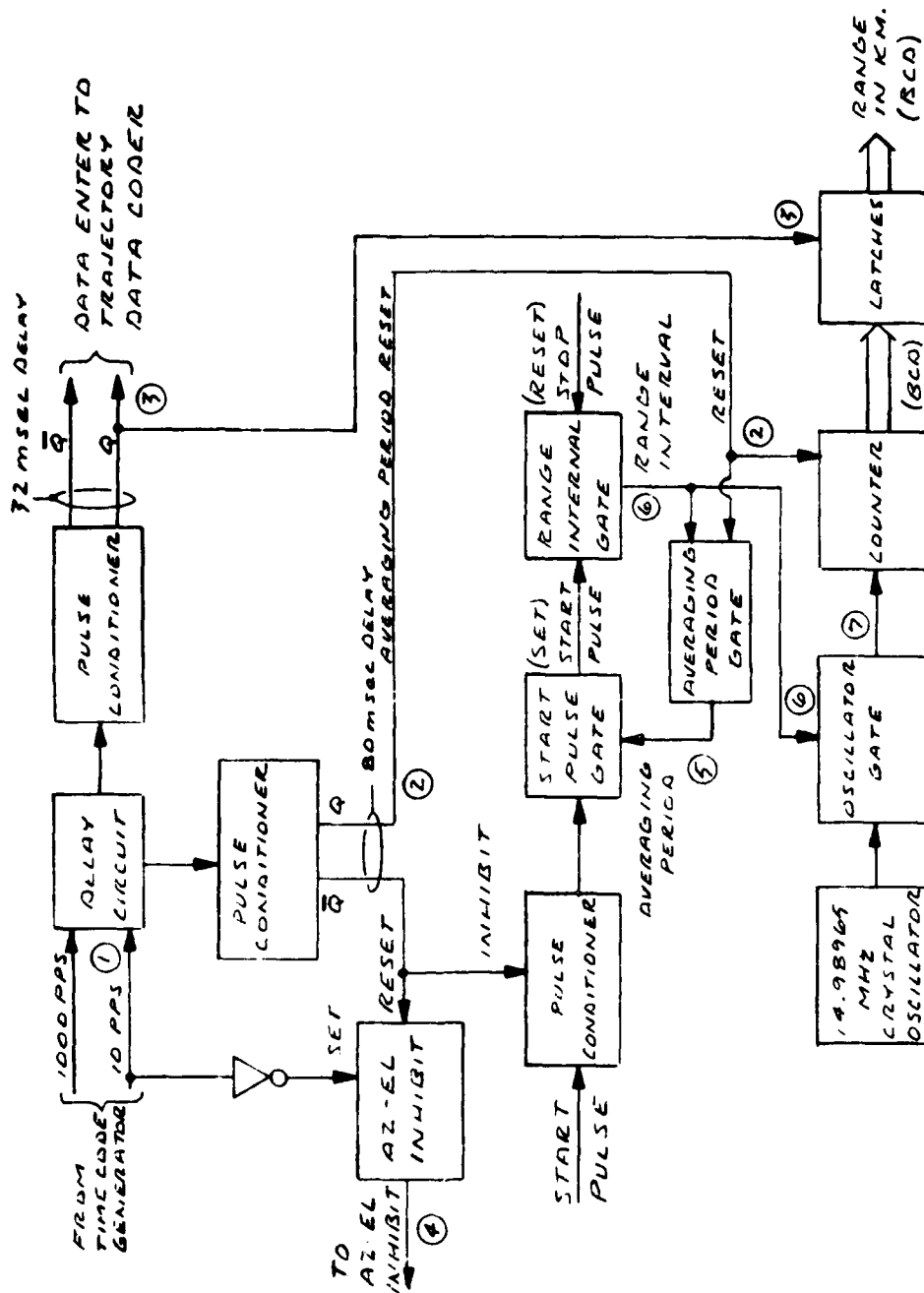


Figure 5. Time Interval Counter Block Diagram

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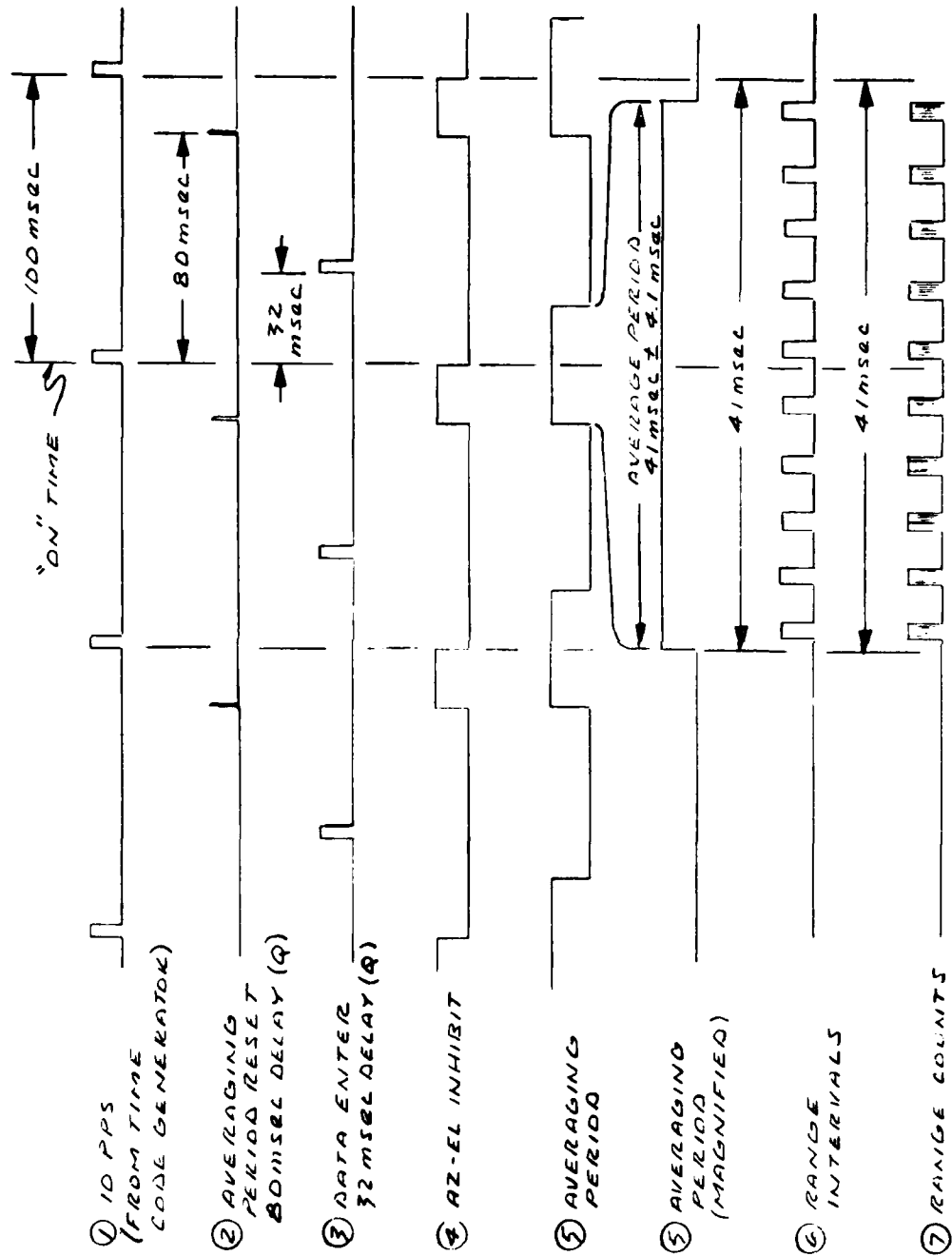


Figure 6. Time Interval Counter Waveforms

(6) . The start pulses are buffered by IC404C and the stop pulses are buffered by IC404B.

An oscillator gate (IC407C) is opened by the ten range intervals (6) allowing pulses from a 14.98965 MHz crystal oscillator (IC404A and IC406B) to enter a counter (IC409-419). The crystal frequency was chosen such that the counter BCD output is equal to the range in kilometers. Since ten range intervals are counted, the counter output is available to .001 Km; however, it is used to only .01 Km. This averaging process provides a more stable range readout. The counter is reset by the averaging period reset pulse (2). The counter BCD output is latched (IC413-416) by the data enter pulse and then entered to the front panel display and to the Trajectory Data Coder when it receives the data enter pulse (3) generated in the delay circuit. The start pulse conditioner (IC406A) receives an inhibit pulse (\bar{Q}) which is the inverted averaging period reset pulse. This inhibit technique prevents the possibility of missing any counts during the short time the counter is being reset.

The data enter pulse (3) from the delay circuit is also used in the Trajectory Data Coder card to parallel enter all of the data. The data enter pulse is delayed 32 msec after the 10 pps "on" time in the delay circuit of IC402 and conditioned to provide an inverted (\bar{Q}) and non-inverted (Q) output by IC403. The delay pulse occurs approximately 10 msec after the end of the averaging period. The inverted data enter pulse (\bar{Q}) is used in the Trajectory Data Coder to correct for bit one delay in timing, caused by the finite length of the data enter pulse.

The Az-El inhibit pulse (4) inhibits the Az-El digital displays at the 10 pps "on" time. The 10 pps clock to the inhibit circuit is inverted by IC404F and sets IC405. The inhibit circuit (IC405) is then reset by the inverted 80 msec delay pulse (\bar{Q}) from the delay circuit. The data enter pulse enters the parallel Az-El BCD data into the Trajectory Data Coder 32 msec after the 10 pps "on" time. The inhibit pulse allows the sampled data to correspond exactly with the "on" time from the time code generator.

2.1.5 Trajectory Data Coder Card (OSU Drawing C95GE03)

The Trajectory Data Coder (Figure 7) formats the parallel BCD trajectory data into a serial PCM data stream suitable for recording on magnetic tape. The 100 bit PCM code frame consists of an 8 bit frame sync, 3 spare bits, 9 status indicator bits, 24 bits for time, 16 bits for El angle, 2 spare bits,

The diagram illustrates a digital data transmission system. It starts with a 1PPS input, which is connected to a .1 SEC COUNTER. The output of the .1 SEC COUNTER is connected to a BIT CLOCK SHAPER. The BIT CLOCK SHAPER has two outputs: one labeled 10PPS and another labeled 100PPS. The 10PPS output is connected to a N/12-L TO BIPHASE-L CONVERTER. The 100PPS output is connected to a LINE DRIVER. The LINE DRIVER is connected to a SERIAL OUTPUT (N/12-L). The SERIAL OUTPUT is connected to a PARALLEL TO SERIAL SHIFT REGISTER. The shift register has 100 bits, labeled BIT 1 to BIT 100. The output of the shift register is connected to a BUFFER and STATUS INDICATORS. The diagram also shows timing waveforms for 1PPS, 10PPS, 100PPS, and 1000PPS, and a 32 msec time scale.

20

18 bits for Az angle, and 20 bits for slant range. The format is arranged so that five "1's" never occur in sequence; therefore, the frame sync pattern of "11111011" is unique. (Numbers in parentheses which follows refer to the waveforms numbered in Figure 7.)

The clock pulses to the Trajectory Data Coder are from the time code generator (1), (3), and (5). They are reshaped by the clock shaper which consists of one-shot multivibrators (IC205 and IC204A). The 10 pps clock (4) is counted by a 4-bit binary counter (IC203) which is reset by the 1 pps clock (2) to provide BCD time for each .1 sec. The 1000 pps clock (6) is used as the bit clock in the parallel-to-serial shift register (IC206-218). The reshaped 10 pps (4) and 1000 pps (6) clocks are fed to the time interval counter card where they are used to generate the data enter pulses (8,9). The data enter pulses enter the parallel data into the shift registers. The data enter pulses are delayed 32 msec beyond the 10 pps "on" time to allow the time interval counter enough time to accomplish the range averaging.

The 1000 pps bit clock is made symmetrical (7) in the bit clock shaper (IC204B) and used with the NRZ-L code from the parallel-to-serial shift register to convert the data to a Biphase Level PCM code (IC202). A dual line driver (IC201) is used to provide the trajectory data output and the trajectory data monitor. The inverted data enter pulse (\bar{Q}) is also used in the line driver to correct bit one timing errors due to the delay in the parallel enter pulse to the parallel-to-serial shift register. The line driver is capable of providing 250 ma of current. The trajectory data code is provided on BNC jacks on the front and rear panels for recording on magnetic tape. The trajectory code can also be selected as the input to the microcomputer by a front panel pushbutton switch.

Nine status indicators are also included in the PCM code. Six of the bits indicate the mode (slave, manual, or auto) of the Az and El axes of the tracking antenna system used with the Tradat V system. The status indications are buffered so that an indication is given by any voltage between +5v and +32v. Three other bits may be used as flag bits to indicate such events as rocket liftoff. A flag indication is given by a switch closure between the flag line and its return line.

2.1.6 FM Discriminator

A Tri-Com model 442P discriminator with a 70 KHz model 442B channel selector

and a 4950 Hz model 442 CA/CD lowpass filter is used in the Tradat V chassis. The discriminator is mounted directly in the Tradat chassis through the front panel. The video from the RF receiver is entered into the discriminator and the discriminator output is entered into the Bit Sync card when the "DISC" "Input Source" switch is depressed on the Tradat console front panel.

2.2 Physical description

The Tradat V system consists of the following components (Refer to Figures 1 and 2):

1. Time code generator/reader (1 3/4" rack height).
2. Tradat V console (5 1/4" rack height).
3. Transmitter (3 1/2" rack height with power supply mounted in rear of cabinet).
4. Line printer (such as Anadex Model DP-8000).

2.2.1 Chassis

The Tradat V chassis consists of the following components (Refer to Figure 8 for layout):

1. Double width (9") wire-wrap plug-in electronic cards.
 - a. Ranging Code Generator and Sync Detector
 - b. Trajectory Data Coder
 - c. Microcomputer
2. Single width (4.5") wire-wrap plug-in electronic cards.
 - a. Time Interval Counter
 - b. Program
 - c. Bit Sync
3. Power Supplies
 - a. ± 12 vdc and -5 vdc
 - b. +5 vdc
4. Tri-Com model 442-P FM discriminator
 - a. 70 KHz (channel 18) channel selector, model 442B.
 - b. 4950 Hz lowpass filter, model 442CA/CD.

2.2.2 Front Panel

The front panel (Figure 9) is divided into functional sections as follows:

1. Discriminator
2. Range (Offset Adjust)

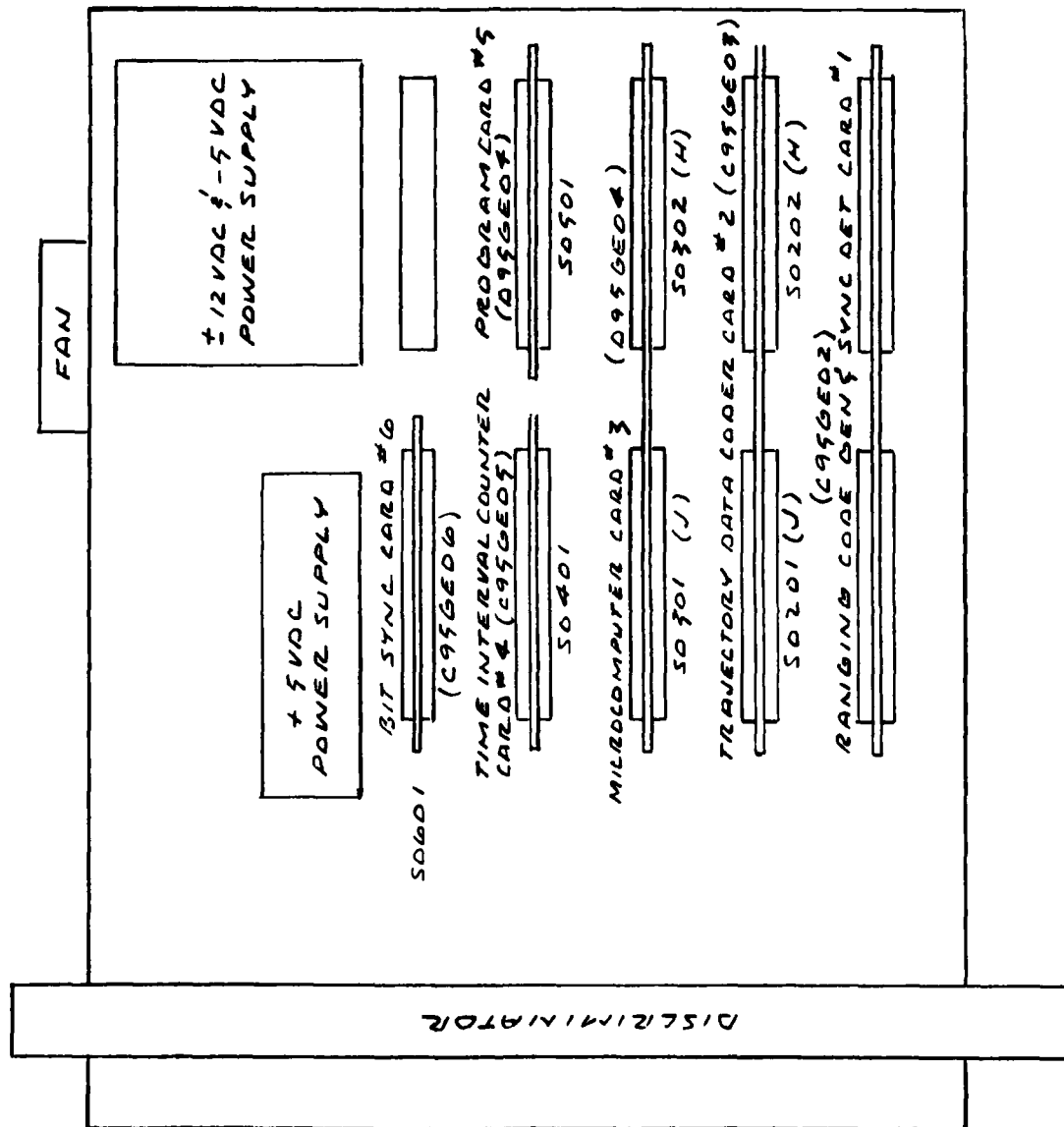


Figure 8. Tradat Chassis Layout

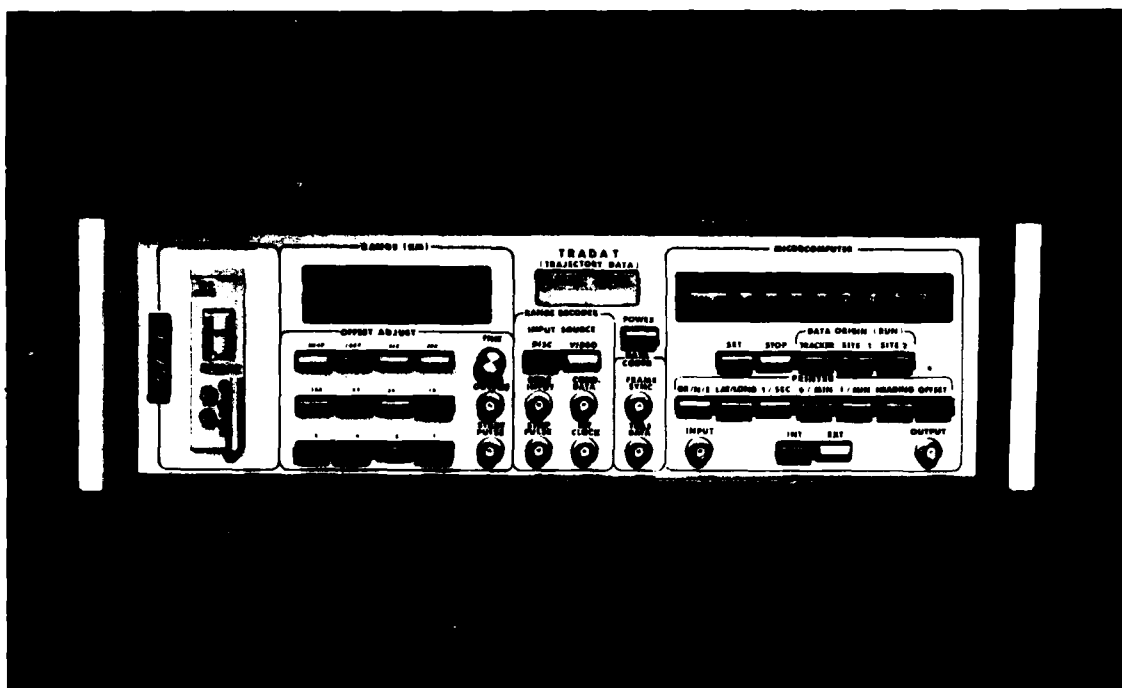


Figure 9. Tradat V Console Front Panel

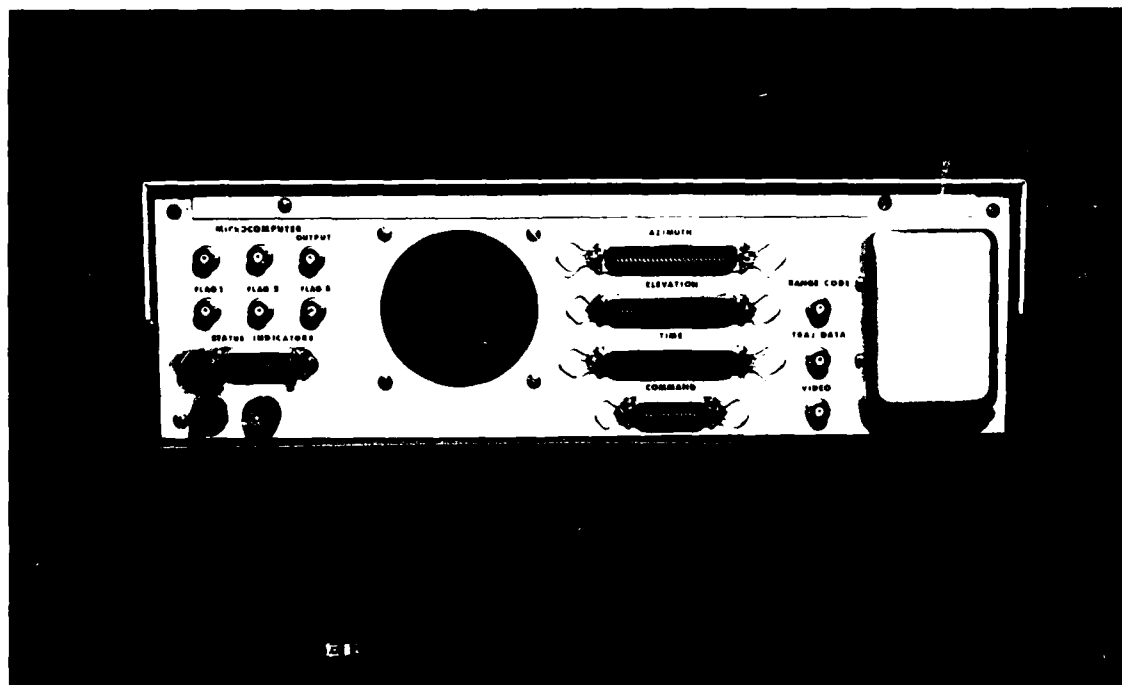


Figure 10. Tradat V Console Rear Panel

3. Range Decoder
4. Data Coder
5. Microcomputer

The microcomputer section will be discussed in section 3.0.

All of the front panel switches are of the non-lighted status indicator type, i.e., a color appears on the front of the pushbutton when it is depressed. The colors were selected such that all engaged switches appear green in the normal operating mode. A yellow indication by an engaged switch indicates a mode that is used less often than the normal operating mode. The system will operate with a yellow indication but the switch mode should be checked to see if it is in the required mode. The only switch on the trajectory part of the Tradat system that gives a yellow indication is the "Video" "Input Source" switch on the Range Decoder section. Tradat V has normally been used with FM telemetry systems and the "Video" "Input Source" switch is engaged only when Tradat is used with PCM telemetry systems.

2.2.2.1 Discriminator

The discriminator has the following front panel controls, indicators, and test points:

<u>Item</u>	<u>Function</u>
Zero Control	Adjusts the data output to zero when the SCO input is at center frequency.
Gain Control	Adjusts the data output to any desired value between 0.1 and 10 volts when the SCO is at bandedge.
Output Meter	Indicates the approximate location of the SCO in the band.
"In" Test Point	Selected SCO signal, following bandpass input filter.
"Out" Test Point	Data at lowpass filter output, but before gain control, deviation polarity connection, and output.
"Gnd" Test Point	Signal ground for "In" and "Out" test points.

Care should be used when setting up the airborne SCO to note whether the output of the ranging receiver is a dc or an ac output. The SCO would have to be set up zero to +5 volts for dc and + 2.5 volts for ac. The noise output of the receiver should be examined to verify that it is below 5 volts for DC and + 2.5 volts for AC. This will prevent the SCO from going out of band and affecting adjacent channels. A squelch circuit on the ranging receiver is not

necessary if the receiver output can be kept within the input limits of the SCO.

The discriminator zero control should be adjusted to give zero output when the SCO is at center frequency. The Gain Control adjustment is not critical and the output can be set anywhere between .5 volts to 10 volts peak-to-peak. After the ranging system has been initialized, the discriminator controls should not be changed or the range will change.

2.2.2.2 Range (Offset Adjust)

The Range (Offset Adjust) section of the front panel consists of the following indicators, adjustments, and monitor points:

<u>Item</u>	<u>Function</u>
"RANGE (Km)" Display	Five LED digital displays for range readout to .01 Km.
"OFFSET ADJUST" Switches (Green)	12 pushbutton switches (push-push type) for adjusting the range to allow for variable loop delays.
"FINE" Adjust	A ten turn potentiometer providing a fine adjustment to the range.
"CODE OUTPUT" Monitor	Monitors the ranging code output to the ranging transmitter.
"START PULSE" Monitor	Monitors the start pulse to the Time Interval Counter Card.

The offset adjust pushbutton switches allow the range to be adjusted in decreasing binary time intervals between 2048 microseconds (306.99 Km) and 1 microsecond (.15 Km). The fine adjust potentiometer allows the range to be adjusted slightly more than 1 microsecond. The range can be adjusted to any range from .01 Km to the maximum range of 613.98 Km. These range adjustments allow the Tradat V system to be used with different telemetry systems with different loop delays affected by such things as different receiver IF filters, different receiver video filters and levels, etc.

The start pulse is equivalent to a subframe sync pulse of the PCM range code. It can be used as an oscilloscope sync pulse for viewing the range coder or decoder waveforms. Since the start pulse is a subframe sync, the ranging code waveform appears as two overlapping traces on an oscilloscope, one normal and the other inverted, when the start pulse is used as the scope sync.

2.2.2.3 Range Decoder

The ranging decoder section of the front panel consists of the following switches and monitor points:

<u>Item</u>	<u>Function</u>
"DISC" (Green) "Video" (Yellow) "Input Source" Switch	Two interlocking pushbuttons to select the ranging data source; "DISC" for FM and "Video" for PCM telemetry systems.
"CODE INPUT" Monitor	Monitors the selected ranging data source ("DISC" or "VIDEO") to the Bit Synchronizer Card. This monitor point has a 10K isolation resistor & may be affected by load impedance, particularly when monitoring high bit rate PCM codes.
"COND DATA" Monitor	Monitors the range code as reconstructed by the Bit Synchronizer Card.
"STOP PULSE" Monitor	Monitors the stop pulse to the Time Interval Counter Card.
"BIT CLOCK" Monitor	Monitors the reconstructed ranging code bit clock from the Bit Synchronizer Card.

The Tradat V console can be checked in a closed loop manner by cabling the "CODE OUTPUT" to the "CODE INPUT" and selecting the "VIDEO" as the "INPUT SOURCE" on the front panel. Be sure to turn the RF receiver off if it is cabled to the Tradat V console. All of the waveforms and functions can be tested in this manner without the need for the airborne part of the ranging system.

2.2.2.4 Data Coder

The Data Coder section of the front panel consists of the following:

<u>Item</u>	<u>Function</u>
"POWER" Switch (Green)	A pushbutton switch (push-push type) for turning the console on and off.
"FRAME SYNC" Monitor	Monitors the trajectory data code frame sync.
"TRAJ DATA" Monitor	Monitors the serial trajectory data code out of the Trajectory Data Coder Card.

The "POWER" switch is not part of the Data Coder but is physically located right above it. The "POWER" switch turns power on and off to the entire Tradat V console.

The "FRAME SYNC" monitor is a buffered output of the "DATA ENTER" pulse from the Trajectory Data Coder Card. This frame sync pulse can be used to sync an oscilloscope, to view the trajectory data code when troubleshooting the trajectory data coder card or input circuit on the microprocessor.

The "Trajectory Data" monitor receives its signal from a line driver capable of driving 250 ma. Therefore, a magnetic tape recorder or other device can be driven by this monitor without loading the signal.

2.2.3 Rear Panel

The trajectory system section of the rear panel (Figure 10) consists of the following:

<u>Item</u>	<u>Function</u>
Blower	For keeping internal components cool.
"AZIMUTH" Socket	Azimuth angle BCD input from tracker.
"ELEVATION" Socket	Elevation angle BCD input from tracker
"TIME" Socket	BCD time and clock pulses from time code generator.
"COMMAND" Socket	Command inputs and verification outputs to the command system (optional equipment).
"RANGE CODE" Output (BNC)	PCM range code modulation to ranging transmitter.
"TRAJ. DATA" Output (BNC)	Trajectory serial data output, for recording on magnetic tape. (Provides 250 ma of drive current.)
"VIDEO" Input (BNC)	Video input from receiver.
Raised Cover Plate	Provides protection for protruding discriminator connector.
AC Power Cord	Provides 115 VAC power.
"FUSE"	1.5 Amp protective fuse.
"STATUS INDICATORS" Socket	Status indicator inputs from the tracker to the Trajectory Data Coder Card.
"FLAC 1", "FLAG 2", "FLAG 3" INPUTS (BNC)	Remote flag indicators to mark any event vs. time from any external device to the Trajectory Data Coder Card.

3.0 MICROCOMPUTER

The microcomputer section of the Tradat V console accepts the trajectory data code via front panel pushbutton switches from either the Tradat V system real time (during rocket or balloon flights) or from a magnetic tape recorder (when making post-flight trajectory records). The front panel of the Tradat V console containing the microcomputer controls is shown in Figure 8. As mentioned in section 2.1.5, the trajectory data code consists of status indicator information, time, and the raw spherical coordinates (Az, El, and slant range) of the vehicle location. The microcomputer transforms the raw spherical coordinate data into trajectory data based on an ellipsoidal Earth shape. The computed data can be referenced to the tracker site or to one of two offset site locations, such as a rocket launch site. The coordinates of the tracker and offset sites are entered into the microcomputer via front panel digiswitches and a "SET" pushbutton while the microcomputer is in the "STOP" mode. The microcomputer output is an ASCII RS 232 9600 baud serial code available on the front or rear panel of the Tradat V console. The output is normally used to drive a printer of adequate printing speed, such as the Anadex model DP8000. Printing rates of 1/sec, 6/min, and 1/min are selectable via front panel pushbutton switches. A heading may be printed while the microcomputer is in the "STOP" mode by depressing the "HEADING" momentary pushbutton switch. The coordinates of the tracker and offset sites are included in the heading printout. The coordinates may also be printed out by depressing the "COORD" pushbutton while the microcomputer is in the "STOP" mode or one of the "RUN" modes. A sample printout is shown in Figure 11. The heading consists of a title, places for recording pertinent launch information, coordinates of tracker and offset sites, the computed range (less than 100 Km) and azimuth from the tracker to site 1, status indicator definitions, and data column headings. A printed data line consists of the time; status indicators; mean sea level altitude in Km; Az, El, and slant range in Km to the vehicle from the front panel selected data origin (Tracker, Site 1, or Site 2); and selected, via the front panel pushbutton switches, either the vehicle ground range, distance North, and distance East in Km or the vehicle latitude and longitude in degrees. The sign convention used is that minus (-) latitude is South, minus (-) longitude is East, minus (-) distance North is South and minus (-) distance East is West.

AFGL/OBUI TRADAT TRAJECTORY DATA

VEHICLE:

LAUNCH DATE:

LAUNCH TIME:

LAUNCH SITE:

COORDINATES:	ALT(KM)	LAT(DEC)	LONG(DEC)
TRACKER	+00.4557	+30.0000	+088.0000
SITE 1	+00.9667	+30.0000	+089.0000
SITE 2	+00.4358	+31.0000	+087.0000

TRACKER TO SITE1: RANGE 095.510 KM AZ 270.00 DEG

STATUS INDICATOR DEFINITIONS:

1 ORIGIN (1,2); 2 AZ MODE; 3 EL MODE; 4 FLAG 1; 5 FLAG 2; 6 FLAG 3

TIME HH:MM:SS	STATUS 123456	MSLA (KM)	GR/N/ OR (KM) OR (DEG)	LAT/LONG (DEG)	AZ (DEG)	EL (DEG)	SR (KM)
06:10:02	TSS000	ALT000.66	LAT+30.0091 LONG+088.0000	AZ360.00	EL00.00	SR001.01	
06:10:03	TSS000	ALT000.66	LAT+30.0090 LONG+088.0000	AZ360.00	EL00.00	SR001.00	
06:10:04	TSS000	ALT000.66	LAT+30.0090 LONG+088.0000	AZ360.00	EL00.00	SR001.00	
06:10:05	TSS000	ALT000.66	LAT+30.0090 LONG+088.0000	AZ360.00	EL00.00	SR001.00	
06:10:07	ISS000	ALT000.66	LAT+30.0090 LONG+088.0000	AZ089.16	EL00.00	SR096.50	
06:10:08	ISS000	ALT000.66	LAT+30.0090 LONG+088.0000	AZ089.16	EL00.00	SR096.50	
06:10:09	ISS000	ALT000.66	LAT+30.0091 LONG+088.0000	AZ089.15	EL00.00	SR096.50	
06:10:10	ISS000	ALT000.66	LAT+30.0091 LONG+088.0000	AZ089.15	EL00.00	SR096.50	
06:10:11	ISS000	ALT000.66	LAT+30.0091 LONG+088.0000	AZ089.15	EL00.00	SR096.50	
06:10:13	2SS000	ALT000.66	LAT+30.0090 LONG+088.0000	AZ221.40	EL00.00	SR145.90	
06:10:14	2SS000	ALT000.66	LAT+30.0090 LONG+088.0000	AZ221.40	EL00.00	SR145.90	
06:10:15	2SS000	ALT000.66	LAT+30.0091 LONG+088.0000	AZ221.40	EL00.00	SR145.89	
06:10:16	2SS000	ALT000.66	LAT+30.0091 LONG+088.0000	AZ221.40	EL00.00	SR145.89	
06:10:17	2SS000	ALT000.66	GR145.57 N-109.85 E-095.51	AZ221.40	EL00.00	SR145.89	
06:10:23	ISS000	ALT000.66	GR096.51 N+001.01 E+096.50	AZ089.16	EL00.00	SR096.50	
06:10:25	TSS000	ALT000.66	GR001.01 N+001.01 E-000.00	AZ360.00	EL00.00	SR001.01	
06:10:26	TSS000	ALT000.66	GR001.01 N+001.01 E-000.00	AZ360.00	EL00.00	SR001.00	
06:10:27	TSS000	ALT000.66	LAT+30.0091 LONG+088.0000	AZ360.00	EL00.00	SR001.01	
06:10:28	TSS000	ALT000.66	GR001.01 N+001.01 E-000.00	AZ360.00	EL00.00	SR001.01	
06:10:29	TSS000	ALT000.66	GR001.01 N+001.01 E-000.00	AZ360.00	EL00.00	SR001.01	
06:10:31	ISS000	ALT000.66	GR096.51 N+001.01 E+096.50	AZ089.15	EL00.00	SR096.50	
06:10:32	ISS000	ALT000.66	GR096.51 N+001.01 E+096.50	AZ089.16	EL00.00	SR096.50	
06:10:33	ISS000	ALT000.66	GR096.51 N+001.01 E+096.50	AZ089.15	EL00.00	SR096.50	
06:10:35	2SS000	ALT000.66	GR145.57 N-109.85 E-095.51	AZ221.40	EL00.00	SR145.89	
06:10:36	2SS000	ALT000.66	GR145.57 N-109.85 E-095.51	AZ221.40	EL00.00	SR145.89	

COORDINATES:	ALT(KM)	LAT(DEC)	LONG(DEC)
TRACKER	+00.4557	+30.0000	+088.0000
SITE 1	+00.9667	+30.0000	+089.0000
SITE 2	+00.4358	+31.0000	+087.0000

Figure 11. Tradat Microcomputer Printout

3.1 Derivation of Equations

The geocentric coordinate system (Figure 12) was selected with the vertical (ϕ_g) axis through the tracker site, with the East (E_g) axis through the equator, and with the North (N_g) axis on the longitudinal plane through the tracker site. The tracker site coordinate system data is transformed to geocentric coordinate data by rotating the tracker site data through an angle equal to the tracker site latitude and then translating the tracker site data to the Earth's center. The geocentric coordinate system data may then be transformed to any location on the Earth by a translation to the Earth's surface and then two rotations equal to the offset latitude (ϕ_o) and the longitude difference ($\Delta\lambda$) between the tracker site and the offset site.

3.1.1 Geocentric Transformation

The tracker site rectangular coordinate data is derived from the spherical coordinate data (tracker data) as follows (Figure 13):

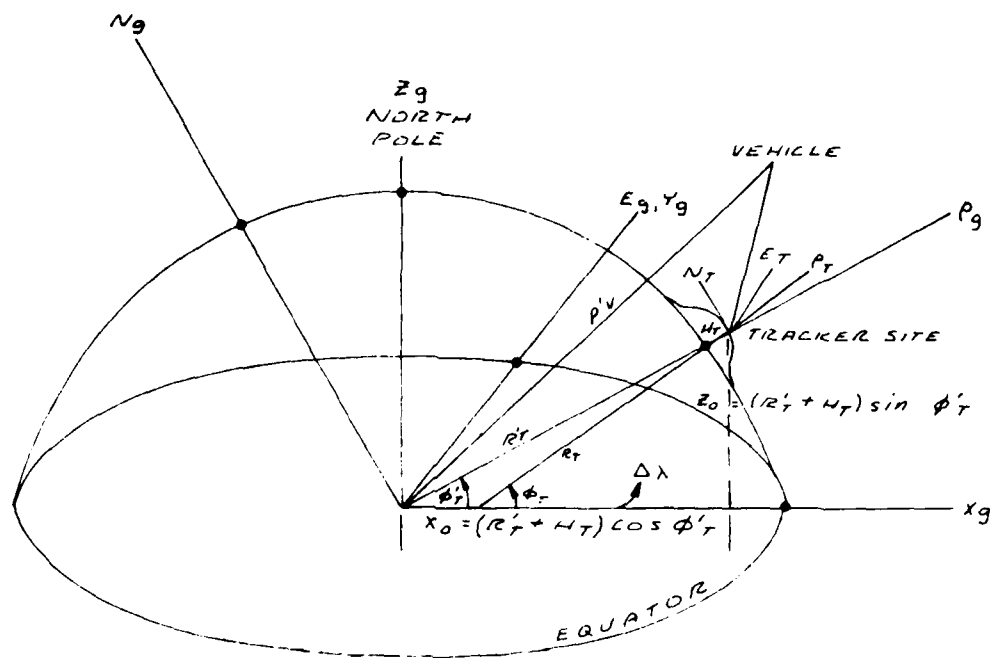
- (1) $GR_p = SR_p \cos EL_p$
- (2) $A_p = SR_p \sin EL_p$
- (3) $N_p = GR_p \cos AZ_p$
- (4) $E_p = GR_p \sin AZ_p$

From Figure 12, the offsets from the tracker site to geocentric coordinates are:

- (5) $X_o = (R_T' + H_T) \cos \phi_T'$
- (6) $Y_o = 0$
- (7) $Z_o = (R_T' + H_T) \sin \phi_T'$
- (8) $R_T' = 6378.185 - 21.39 \sin^2 \phi_T$
- (9) $\phi_T' = \phi_T - e^2 \sin \phi_T / (1 - e^2 \sin^2 \phi_T)$

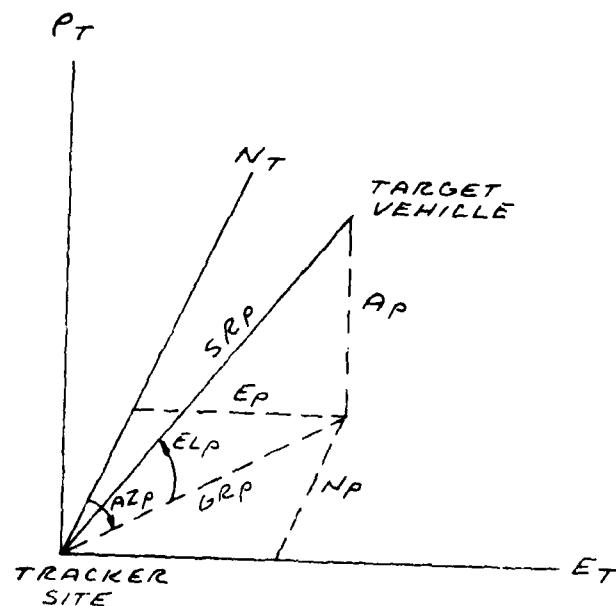
See section 3.1.4 equations (50) and (54) for the derivation of equations (8) and (9).

The Euler angles used in these coordinate transformations are found in Figure 14. The Euler matrix $|E|$ is for transforming from geocentric to tracker site coordinates. The transpose of the Euler matrix $|E'|$ must be used to go from the tracker site to geocentric coordinates. With the rotation angles $\alpha = 0$ and $\beta = \phi_T$, the transformation from tracker site to geocentric coordinates is:



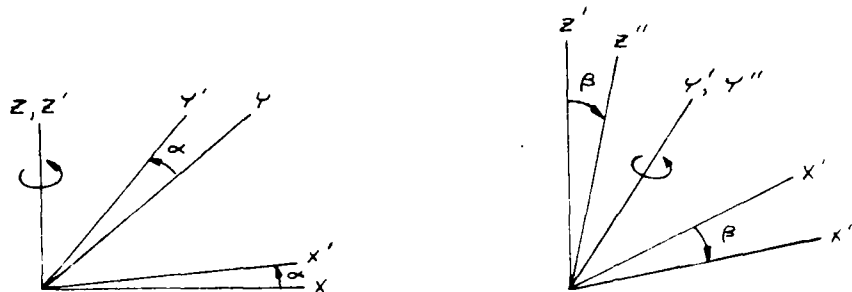
- ϕ_T = Geodetic tracker site latitude.
 ϕ_T' = Geocentric tracker site latitude.
 R_T = Geodetic Earth radius at tracker site.
 R_T' = Geocentric Earth radius at tracker site.
 e = eccentricity (.0818291922).
 $\Delta\lambda$ = Longitude offset from tracker to offset site.
 H_T = Tracker site altitude.
 (Subscript "0" defines offset site.)
 C_T = Vertical tracker site axis.
 E_T = East tracker site axis.
 N_T = North tracker site axis.

Figure 12. Geocentric Coordinate System



AZ_p = Azimuth angle
 EL_p = Elevation angle
 SR_p = Slant range
 GR_p = Ground range
 A_p = Altitude
 N_p = Distance North
 E_p = Distance East

Figure 13. Tracker Site Coordinate System



$$(15) \quad |E| = \begin{vmatrix} -\sin\alpha & \cos\alpha & 0 \\ -\sin\beta \times \cos\alpha & -\sin\beta \times \sin\alpha & \cos\beta \\ \cos\beta \times \cos\alpha & \cos\beta \times \sin\alpha & \sin\beta \end{vmatrix}$$

$$(16) \quad |E'| = \begin{vmatrix} -\sin\alpha & -\sin\beta \times \cos\alpha & \cos\beta & \cos\alpha \\ \cos\alpha & -\sin\beta \times \sin\alpha & \cos\beta \times \sin\alpha & \\ 0 & \cos\beta & \sin\beta & \end{vmatrix}$$

Figure 14. Euler Rotation Matrix

$$(10) \quad \begin{vmatrix} X_v \end{vmatrix} = \begin{vmatrix} E \end{vmatrix} \begin{vmatrix} X_p \end{vmatrix} + \begin{vmatrix} X_o \end{vmatrix}$$

or

$$(11) \quad \begin{vmatrix} X_v \\ Y_v \\ Z_v \end{vmatrix} = \begin{vmatrix} 0 & -\sin \theta_T \cos \theta_T \\ 1 & 0 & 0 \\ 0 & \cos \theta_T \sin \theta_T \end{vmatrix} \begin{vmatrix} E_p \\ N_p \\ A_p \end{vmatrix} + \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix}$$

3.1.2 Offset Site Transformation

The offsets from the geocentric to the offset location on the Earth's surface are (refer to Figure 15):

$$(12) \quad X_{os} = (R_o' + H_o) \cos \theta_o' \cos \Delta \lambda$$

$$(13) \quad Y_{os} = (R_o' + H_o) \cos \theta_o' \sin \Delta \lambda$$

$$(14) \quad Z_{os} = (R_o' + H_o) \sin \theta_o'$$

With the rotation angles $\alpha = \Delta \lambda$ and $\beta = \theta_o'$, the transformation from geocentric to offset site coordinates is (see Figure 15):

$$(17) \quad \begin{vmatrix} X_{po} \end{vmatrix} = \begin{vmatrix} E \end{vmatrix} \left(\begin{vmatrix} X_v \end{vmatrix} - \begin{vmatrix} X_{os} \end{vmatrix} \right)$$

or

$$(18) \quad \begin{vmatrix} E_{po} \\ N_{po} \\ A_{po} \end{vmatrix} = \begin{vmatrix} -\sin & \cos & 0 \\ -\sin \theta_o \cos & -\sin \theta_o \sin & \cos \theta_o \\ \cos \theta_o \cos & \cos \theta_o \sin & \sin \theta_o \end{vmatrix} \left(\begin{vmatrix} X_v \\ Y_v \\ Z_v \end{vmatrix} - \begin{vmatrix} X_{os} \\ Y_{os} \\ Z_{os} \end{vmatrix} \right)$$

The offset site spherical coordinate data is derived from the rectangular coordinate data as follows:

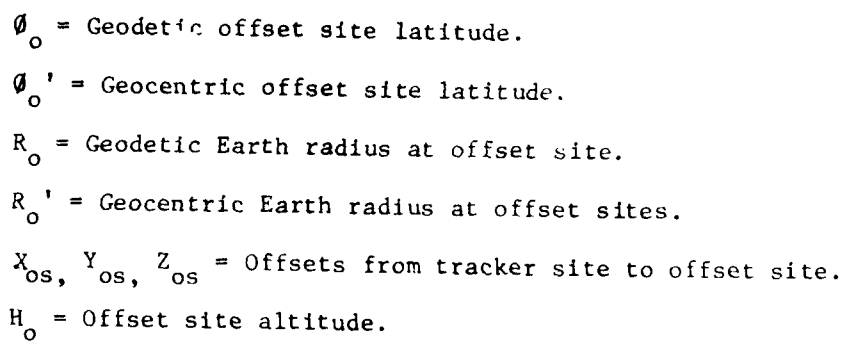
$$(19) \quad GR_{po} = \sqrt{N_{po}^2 + E_{po}^2}$$

$$(20) \quad AZ_{po} = \arctan (E_{po}/N_{po})$$

$$(21) \quad SR_{po} = \sqrt{GR_{po}^2 + A_{po}^2}$$

$$(22) \quad EL_{po} = \arctan (A_{po}/GR_{po})$$

These are the parameters a tracker would display if it were at the offset site tracking the target vehicle.



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3.1.3 Geodetic Transformation

The geodetic coordinates (latitude and longitude) of the subearth point of the target vehicle and the mean sea level altitude of the target vehicle are useful parameters. The longitude of the target vehicle subearth point is from Figure 16:

$$(23) \quad \lambda_v = \lambda_T - \Delta\lambda_v$$

where $(24) \quad \Delta\lambda_v = \arctan (X_v/Y_v)$

The latitude of the target vehicle cannot be determined directly but must be calculated in an iterative loop. The geocentric latitude and altitude are calculated as follows from Figure 16:

$$(25) \quad GR_v = \sqrt{X_v^2 + Y_v^2}$$

$$(26) \quad \phi_g = \arctan (Z_v/GR_v)$$

$$(27) \quad \rho'_v = \sqrt{GR_v^2 + Z_v^2}$$

The equation to be used in the loop is derived using the Law of Sines and Figure 16 as follows:

$$(28) \quad \frac{\sin (\phi_v - \phi_g)}{R_S'} = \frac{\sin (180^\circ - (\phi_v - \phi'_v))}{\rho'_v}$$

Since $\sin \theta = \sin (180^\circ - \theta)$ and assuming small angles:

$$(29) \quad \frac{\phi_v - \phi_g}{R_S'} = \frac{\phi_v - \phi'_v}{\rho'_v}$$

or

$$(30) \quad \phi_v = \phi_g + \frac{R_S' (\phi_v - \phi'_v)}{\rho'_v}$$

where $(31) \quad D = (\phi_v - \phi'_v) = e^2 \sin \phi_v \cos \phi_v / (1 - e^2 \sin^2 \phi_v)$ from section 3.1.4. The iterative loop is initialized as follows:

$$(32) \quad \phi_v = \phi_g$$

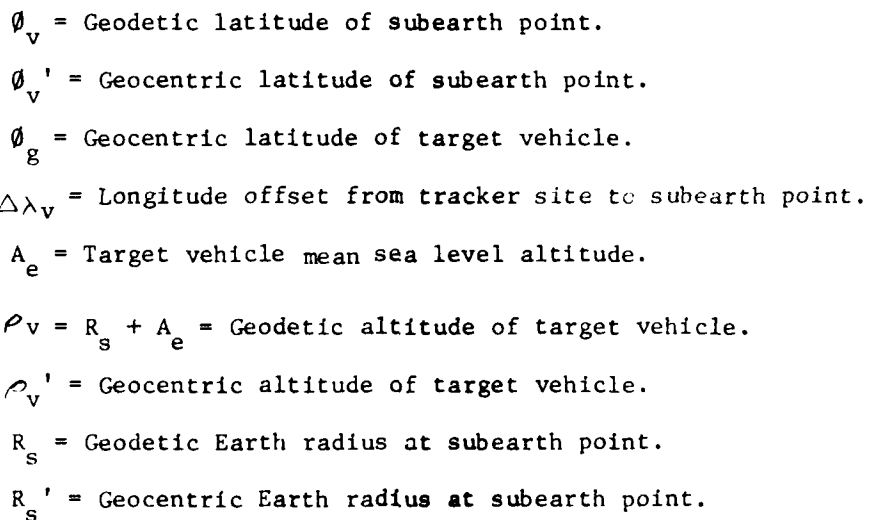
$$(33) \quad D = 0$$

The loop proceeds as follows:

$$(34) \quad R_S' = 6378.185 - 21.39 \sin^2 \phi_v$$

$$(35) \quad D = e^2 \sin \phi_v \cos \phi_v / (1 - e^2 \sin^2 \phi_v)$$

$$(36) \quad \phi_v = \phi_g + \frac{R_S' D}{\rho'_v}$$



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The maximum value of D (occurring at $\phi_v = 45^\circ$) is only $.192^\circ$ and R_s' can only vary a maximum of $.34\%$, so very few iterations are required to find the value of ϕ_v to sufficient accuracy. Two iterations are sufficient to calculate ϕ_v to within $.0001^\circ$.

The target vehicle mean sea level altitude is calculated as follows from Figure 16:

$$(37) \quad A_e = \rho_v' \cos(\phi_v - \phi_g) + R_s' \cos(180^\circ - D)$$

$$(38) \quad A_e = \rho_v' \cos(\phi_v - \phi_g) - R_s' \cos D$$

since (39) $\cos \theta = -\cos(180^\circ - \theta)$ and (40) $a = b \cos C + c \cos B$

The last values to be calculated are the North, East, and ground range distances from the target vehicle subearth point to the data origin. The origin may be the tracker site or some offset location. These values are calculated as follows:

$$(41) \quad R_o' = 6378.185 - 21.39 \sin^2 \phi_o + H_o$$

$$(42) \quad E_{eo} = (\lambda_o - \lambda_v) R_o' \cos \phi_o'$$

$$(43) \quad K_\phi = 110.575 + 1.11 \sin^2 \left(\frac{\phi_o + \phi_v}{2} \right) \text{ (Km/Deg Latitude from Ref. 4)}$$

$$(44) \quad N_{eo} = K_\phi (\phi_v - \phi_o)$$

$$(45) \quad GR_{eo} = \sqrt{E_{ev}^2 + N_{ev}^2}$$

These equations are relative to an offset site. If the equations are required relative to the tracker site, merely replace the "O" subscripts with "T" subscripts.

3.1.4 Earth Spheroid Derivations

The model used for the Earth in the previous calculations is an approximation of an ellipsoidal Earth with these parameters:

$$(46) \quad R_{eq} = 6378.16$$

$$(47) \quad R_{pole} = 6356.77$$

$$(48) \quad f \text{ (flattening)} = 1/298.25$$

$$(49) \quad e \text{ (eccentricity)} = .0818291922$$

The models used for the geocentric and geodetic radii in Km, along with their deviation from the ellipsoidal Earth, are as follows:

$$(50) \quad R' = 6378.185 - 21.39 \sin^2 \phi$$

$$(51) \quad R = 6335.435 + 21.32 \sin^2 \phi$$

The maximum deviation of this Earth model from an ellipsoid is only 25 meters for the geocentric radius and 17 meters for the geodetic radius (Figure 17).

The equation for the angular difference between the geodetic and geocentric latitude is derived as follows:

$$(52) \quad \tan (\phi - \phi') = \frac{e^2 \sin \phi \cos \phi}{\cos^2 \phi + (1 - e^2) \sin^2 \phi} \quad (\text{Ref. 4})$$

Since $(\phi - \phi')$ is always less than $.192^\circ$, the small angle assumption is valid.

$$(53) \quad (\phi - \phi') = \frac{e^2 \sin \phi \cos \phi}{\cos^2 \phi + \sin^2 \phi - e^2 \sin^2 \phi}$$

$$(54) \quad (\phi - \phi') = \frac{e^2 \sin \phi \cos \phi}{1 - e^2 \sin^2 \phi}$$

The effect of the tracker site altitude (H_T) and the offset site altitude (H_O) are so small compared to the Earth's radius that they have a negligible effect on the geodetic latitude.

Refer to Reference 5 for a vigorous treatment of coordinate transformations suitable for use on larger computers.

3.2 Software Description

The microcomputer programs are stored in seven kilobytes of erasable programmable read only memory (EPROM) on the Program Card in the Tradat V console. The working area consists of one kilobyte of random access memory (RAM) on the Microcomputer Card in the Tradat V console. The software for the Tradat V microcomputer was developed on an OSU-built microcomputer development system. The development system (Figure 18) physically consists of a KIM-1 microcomputer card, a KIM-4 mother board, 32 kilobytes of RAM (expandable to 64K), 8 kilobytes of EPROM, EPROM programmer, a mini-floppy disk system, power supplies, and a special purpose Tradat V interface card. The KIM system is based on the MPS6502 microprocessor chip, which is the one selected to be used in the Tradat V microcomputer. Software support includes an assembler-editor, BASIC language, mini-floppy disk control, EPROM programmer, and the normal software included on the KIM-1. The BASIC language was particularly useful in computing trajectory data points to test the computational accuracy of the Tradat V microcomputer. The computational accuracy is within .01 Km for distance, $.01^\circ$ for Az and El angles, and $.0001^\circ$ for latitude and longitude.

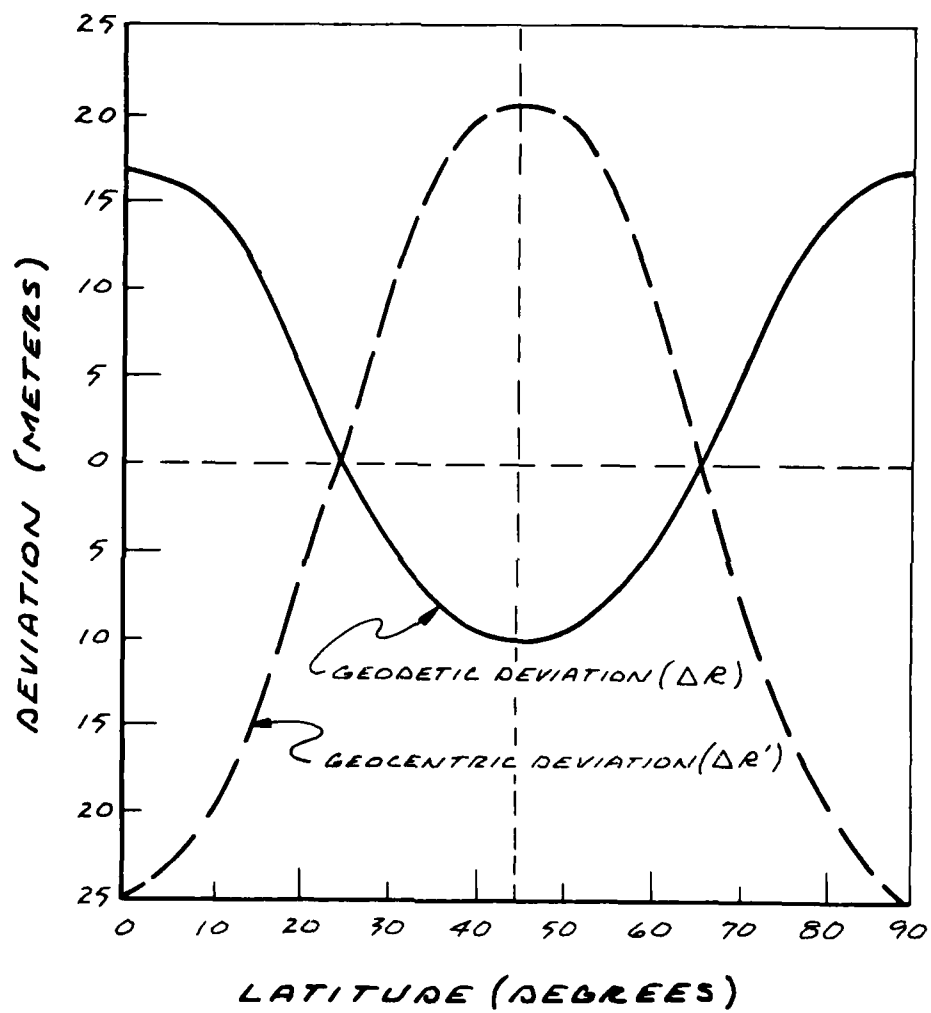


Figure 17. Deviation of Earth Model from an Ellipsoid

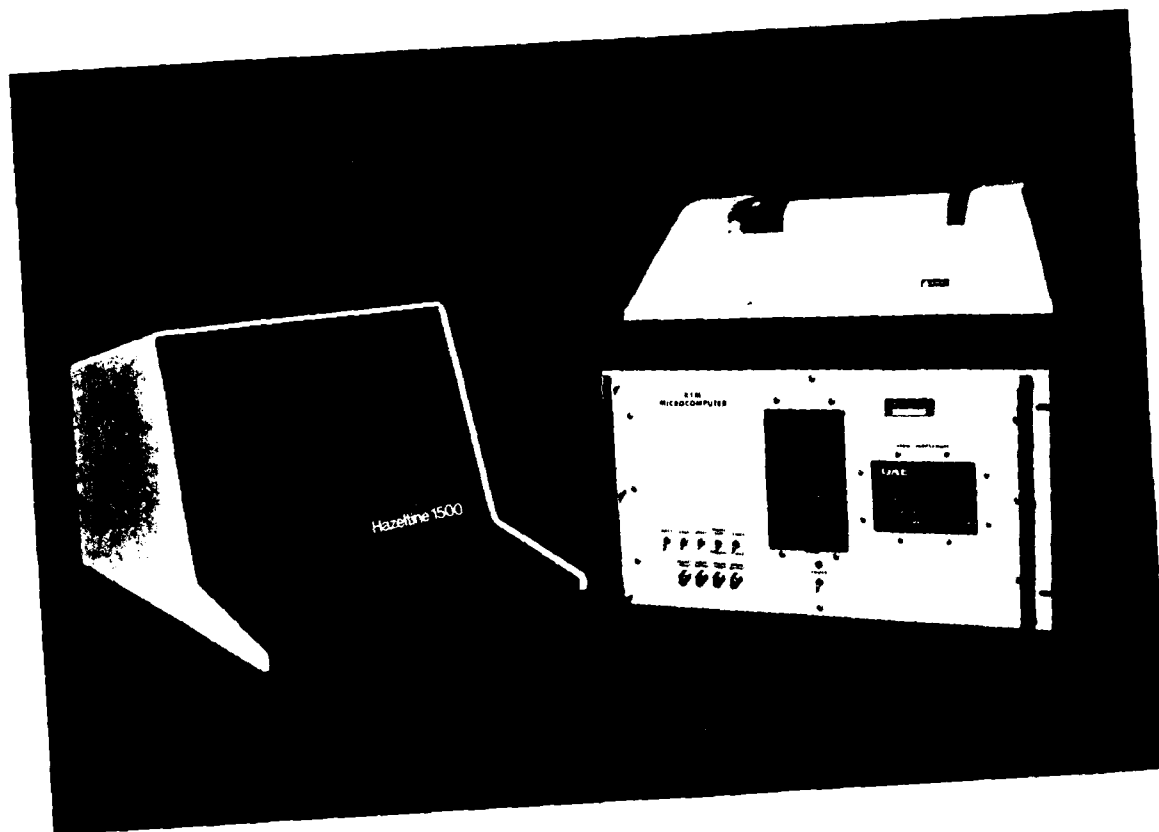


Figure 18. Microcomputer Development System

3.2.1 Main Control Program

A software flow chart of the Main Control Program is shown in Figure 19. At "power on" the system is reset and then initialized by moving certain constants and subroutines to the RAM, by initializing the peripheral interface adapter and output buffer, by running the initial computation program, and by setting the output baud rate.

The program then checks to see if an interrupt flag is present. If no interrupt flag is detected, the program continues on; but if an interrupt flag is detected, the program goes through an interrupt loop. A non-maskable interrupt flag (NMI) is set when the "HEADING" pushbutton is depressed and an interrupt request (IRQ) flag is set when the "COORD" pushbutton is depressed. The heading or data origin coordinates are printed, depending on which pushbutton has been depressed. A sample printout, including the heading and computed data, was shown in Figure 11. The interrupt flag is then cleared before the program returns to check the interrupt flag.

A flowchart describing how the NMI and IRQ interrupt flags are set is included in Figure 19. The primary function of both interrupts is to set an identifying flag (number) in a memory location so the microcomputer will know whether to print a heading or the data origin coordinates. After an NMI is detected, when the "HEADING" pushbutton is depressed, the accumulator and X and Y registers are saved and a check for "STOP" mode occurs. A heading may be printed out only when the microcomputer is in the "STOP" mode. If it is in the "STOP" mode, the heading flag is set, the accumulator and X and Y registers are restored with the previously saved data, and the program will return to the point at which it was interrupted when the "HEADING" pushbutton was depressed. After an IRQ is detected when the "COORD" pushbutton is depressed, the accumulator and X and Y registers are saved and the coordinate flag is set. The accumulator and X and Y registers are restored with the previously saved data and the program will return to the point at which it was interrupted when the "COORD" pushbutton was depressed.

If there is no interrupt flag detected, the program continues and checks to see if the microcomputer is in the "RUN" or "STOP" mode. The microcomputer is in the "RUN" mode when one of the "DATA ORIGIN (RUN)" pushbuttons is depressed. If the microcomputer is in the "STOP" mode, the new data origin pointer is cleared and the microcomputer is checked to see if the "SET" pushbutton is depressed. If it has been depressed, the coordinate data on the thumbwheel digiswitches is

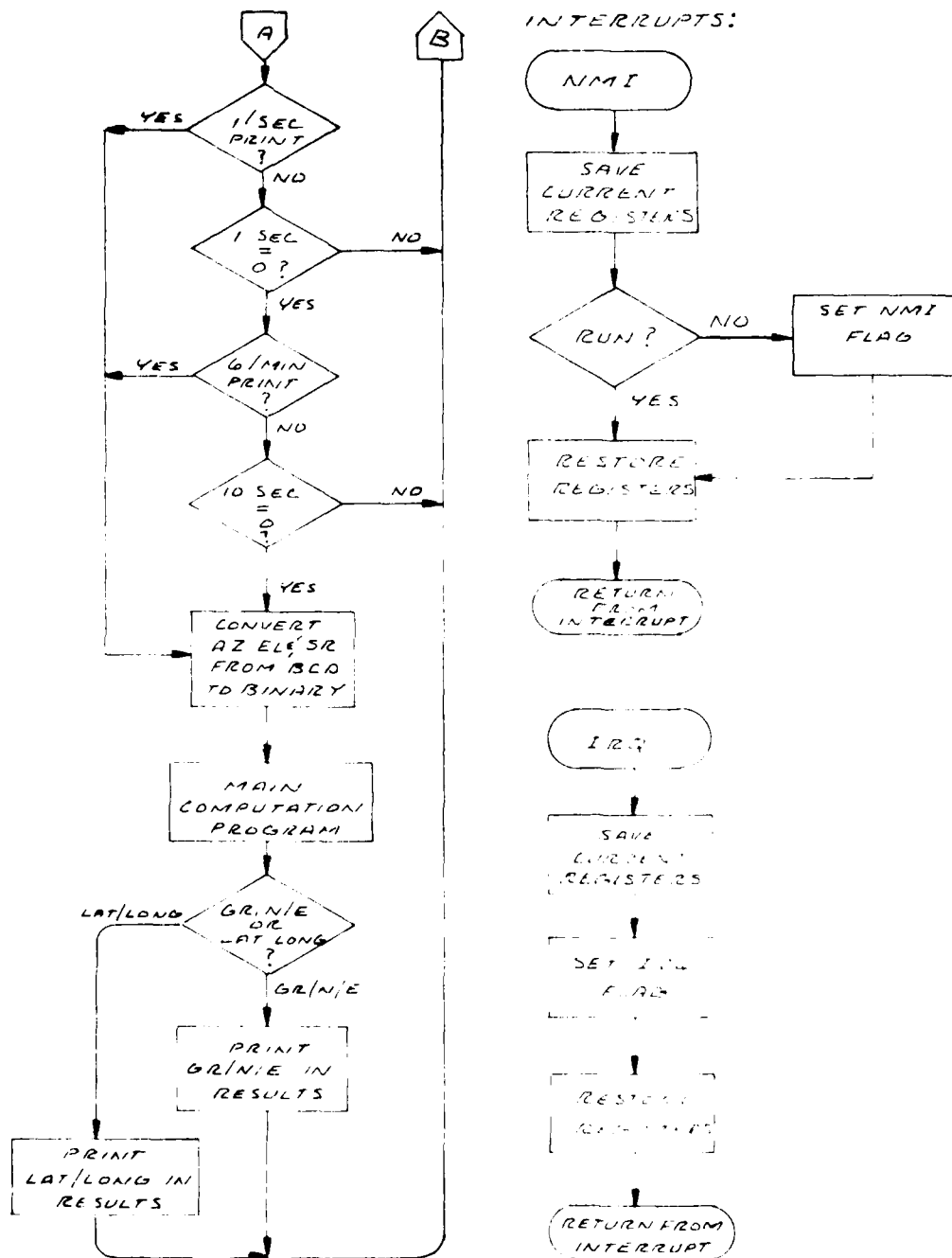


Figure 19. Tradat Microcomputer Software Flow Chart

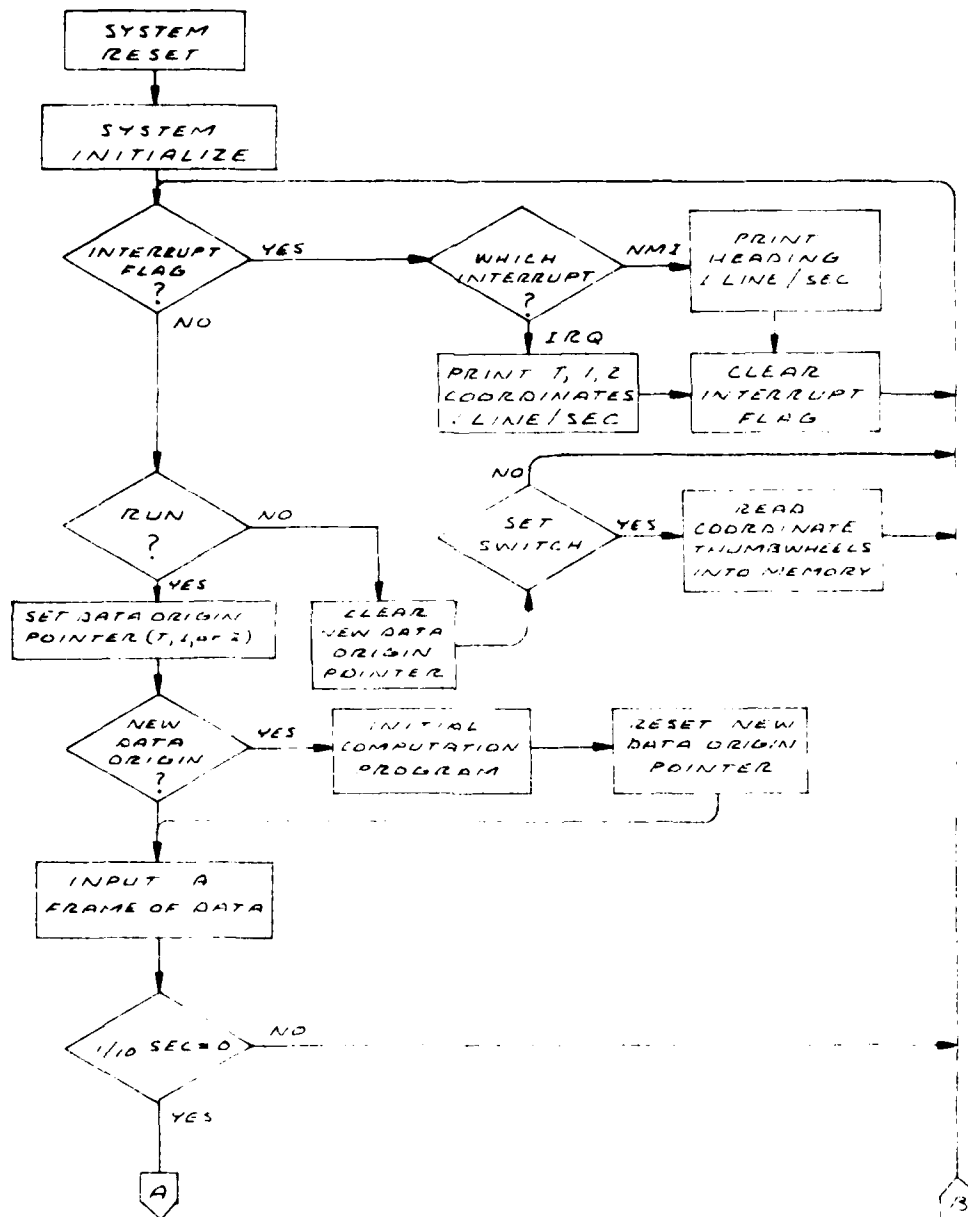


Figure 19. Tradat Microcomputer Software Flow Chart (Con't)

read into memory and the program returns to check the interrupt flag. If the "SET" pushbutton is not depressed, the program goes immediately back to check the interrupt flag.

If the microcomputer is in one of the "RUN" modes, the program sets the data origin pointer and then checks to see if the data origin has been changed. If the data origin has been changed, the program proceeds to a loop that makes initial computations based upon the coordinates of the data origin site. The new data origin pointer is then reset before proceeding on to the next program step. The initial computation program is described further in section 3.2.2.

The next step is to see if there is any data present at the input to the microcomputer. If there is no data present, the program continues in a loop until a frame of data is available. If data is available, the program proceeds to input a frame of trajectory data code.

The program checks to see if the tenths-second word is equal to zero. If it is not zero, the program loops back to check the interrupt flag. If it is zero, the one print per second pushbutton is checked to see if it is depressed. If it is depressed, the program continues on to convert the Az, El, and slant range from BCD to binary; if it is not depressed the program checks to see if the units-second word is zero. If it is not zero, the program loops back to check the interrupt flag; but if it is zero, the six per minute pushbutton is checked to see if it is depressed. If the six per minute pushbutton is depressed, the program continues on to convert the Az, El, and slant range from BCD to binary; if it is not depressed, the program checks to see if the tens-second word is zero. If it is not zero, the program loops back to check the interrupt flag; but if it is zero, the program continues on to convert the Az, El, and slant range from BCD to binary (BCDTB subroutine).

The BCDTB subroutine converts the BCD, Az, El, and slant range data to 40-bit binary numbers. A 40-bit binary number is greater than required for the input data but was selected as the standard fixed point word length due to the accuracy required for some of the intermediate computed values.

The Main Computation Program uses the computed values from the Initial Computation Program and the binary values of the Az, El, and slant range to compute the trajectory data, based on the ellipsoidal Earth shape. The computed data consists of the vehicle geodetic mean sea level altitude in Km; the vehicle ground range, North and East distances in Km along the Earth ellipsoidal surface; the vehicle latitude and longitude in degrees; and the spherical

coordinate data (Az, El, and slant range) of the vehicle relative to the selected data origin site.

The program then checks the output format pushbuttons. If the "GR/N/E" pushbutton is depressed, the vehicle ground range and North and East distances are included in the output format. If the "LAT/LONG" pushbutton is depressed, the vehicle latitude and longitude are included in the output format. After outputting a line of data, the program loops back to check the interrupt flag.

3.2.2 Initial Computation Program

The Initial Computation Program is used to calculate all of the coefficients that are associated with the selected data origin coordinates (altitude, latitude, and longitude of the tracker site or offset site). It is also used to calculate the range and azimuth from the tracker site to site 1. The Initial Computation Program is run only at turn on or when a new data origin is selected. The Initial Computation Program is given in abbreviated form in Table 1. Refer to section 3.1 for parameter definitions. The M and K coefficients that are computed in the Initial Computation Program are stored in random access memory and used in the Main Computation Program. The M coefficients are used in the coordinate transformation computations and the K coefficients (Ref. 6) are used to convert latitude and longitude angular distances into North and East linear distances, measured along the surface of the Earth ellipsoid.

3.2.3 Main Computation Program

The Main Computation Program uses the computed values from the Initial Computation Program and the binary values of the raw spherical coordinate data (Az, El, and slant range) to compute the trajectory data based on the ellipsoidal Earth shape. The computed data consists of the vehicle geodetic mean sea level altitude in Km; the vehicle ground range, North and East distances in Km along the Earth ellipsoidal surface; the vehicle latitude and longitude in degrees; and the spherical coordinate data for the vehicle relative to the selected data origin site. The Main Computation Program is given in abbreviated form in Table 2. The notation $P(R, \theta) \xrightarrow{s} R(X, Y)$ as used in step 1 refers to a polar-to-rectangular transformation and the rotation $R(X, Y) \xrightarrow{s} P(R, \theta)$, as used in step 8, refers to a rectangular-to-polar transformation. The subscript "s" refers to a short cordic rotation and "L" refers to a long cordic rotation. Refer to section 3.1 for parameter definitions and a detailed explanation of the equations and their derivation.

TABLE 1. INITIAL COMPUTATION PROGRAM

1. $R_T' = 6378.185 - 21.39 * \sin^2 \phi_T + H_T$
2. $\Delta\lambda = \lambda_T - \lambda_O$
3. $R_O' = 6378.185 - 21.39 * \sin^2 \phi_T + H_O$
4. $\phi_T' = \phi_T - e^2 * \sin \phi_T * \cos \phi_T / (1 - e^2 \sin^2 \phi_T)$
5. $\phi_O' = \phi_O - e^2 * \sin \phi_O * \cos \phi_O / (1 - e^2 \sin^2 \phi_T)$
(where e = eccentricity of Earth shape ellipsoid)
6. $M_1 = \sin \phi_T * \sin \Delta\lambda$
7. $M_2 = \cos \Delta\lambda$
8. $M_3 = \cos \phi_T * \sin \Delta\lambda$
9. $M_4 = R_T' * \cos \phi_T' * \sin \Delta\lambda$
10. $M_5 = \sin \phi_T * \sin \phi_O + \cos \phi_T * \cos \phi_O$
11. $M_6 = \sin \phi_O * \sin \Delta\lambda$
12. $M_7 = \sin \phi_T * \cos \phi_O - \cos \phi_T * \sin \phi_O$
13. $M_8 = R_O' * (\cos \phi_O' * \sin^2 \Delta\lambda * \sin \phi_O - \sin \phi_O' * \cos \phi_O + \cos \phi_O' * \cos \Delta\lambda * \sin \phi_O) + R_T' * (\sin \phi_T' * \cos \phi_O - \cos \phi_T' * \sin \phi_O)$
14. $M_9 = \cos \phi_O * \sin \Delta\lambda$
15. $M_{10} = R_T' * (\sin \phi_T' * \sin \phi_O + \cos \phi_T' * \cos \phi_O) - R_O' * (\cos \phi_O' * \sin^2 \Delta\lambda * \cos \phi_O + \sin \phi_O' * \sin \phi_O + \cos \phi_O' * \cos^2 \Delta\lambda * \cos \phi_O)$
16. $M_{11} = R_T' * \cos \phi_T'$
17. $M_{12} = R_T' * \sin \phi_T$
18. $K_\lambda = R_O' * \cos \phi_O' \text{ (Km/radian long.)}$
19. $K_\phi = 110.575 + 1.11 * \sin^2 \phi_O \text{ (Km/deg. lat.)}$

TABLE 2. MAIN COMPUTATION PROGRAM

1. $P(SR_p, EL_p) \rightarrow R(GR_p, A_p)$
2. $P(GR_p, AZ_p) \rightarrow R(N_p, E_p)$
3. $E_{po} = N_p * M_1 + E_p * M_2 - A_p * M_3 - M_4$
4. $N_{po} = N_p * M_5 - E_p * M_6 + A_p * M_7 + M_8$
5. $A_{po} = -N_p * M_7 + E_p * M_9 + A_p * M_5 + M_{10}$
6. $X_v = -N_p * \sin \theta_T + A_p * \cos \theta_T + M_{11}$
7. $Z_v = N_p * \cos \theta_T + A_p * \sin \theta_T + M_{12}$
8. $R(N_{po}, E_{po}) \rightarrow P(GR_{po}, AZ_{po})$ (Azimuth Angle)
9. $R(GR_{po}, A_{po}) \rightarrow P(SR_{po}, EL_{po})$ (Slant Range & Elevation Angle)
10. $R(X_v, E_{pL}) \rightarrow P(GR_v, \Delta\lambda_v)$
11. $R(GR_v, Z_{vL}) \rightarrow P(\rho_v', \theta_g)$
12. $\theta_v = \theta_g$; $D = 0$; $N = 2$ (Loop Initialization)
13. $R_s' = 6378.185 - 21.39 * \sin^2 \theta_v$
14. $D = e^2 * \sin \theta_v * \cos \theta_v / (1 - e^2 * \sin^2 \theta_v)$
15. $\theta_v = \theta_g + R_s' * D / \rho_v'$
16. $N = N - 1$
17. IF $N > 0$ GO TO 15
18. $\theta_{vg} = \theta_v - \theta_g$
19. $A_e = \rho_v' * \cos \theta_{vg} - R_s' * \cos D$ (Mean Sea Level Altitude)
20. $K_{\theta v} = 110.575 + 1.11 * \sin^2 \theta_v$ (Km/Deg. Lat.)
21. $K_{\theta vo} = (K_{\theta v} + K_{\theta o}) / 2$ (Avg. Km/Deg. Lat.)
22. $N_{eo} = (\theta_v - \theta_o) * K_{\theta vo}$ (Distance North)
23. $\lambda_v = \lambda_T - \Delta\lambda_v$ (Longitude)
24. $\Delta\lambda_{vo} = \lambda_o + \Delta\lambda_v - \lambda_T$
25. $E_{eo} = \Delta\lambda_{vo} * K_\lambda$ (Distance East)
26. $R(N_{eo}, E_{eo}) \rightarrow P(GR_{eo}, \theta)$ (Ground Range)

Loop
($\theta_v = \text{Latitude}$)

3.2.4 Algorithms

The algorithms developed to complete the trajectory computations are:

1. INPUT - Detects the frame sync word of the trajectory data serial PCM code associated with integral seconds and unpacks the Az, El, slant range, time, and status indicator words and stores them in memory.
2. OUTPUT - Outputs characters to the printer.
3. BTBCD2 - Converts a 40-bit binary number to BCD with 2 decimal places and round off.
4. BTASCI - Converts a 40-bit binary number to a 7 digit ASCII number with 4 decimal places and round off.
5. BTASC2 - Converts a 40-bit binary number to a 5 digit ASCII number with two decimal places and roundoff.
6. ADD - Adds two 40-bit binary numbers.
7. NEG - Negates a 40-bit binary number.
8. MOVE - Moves a 40-bit binary number from one memory location to another.
9. SUB - Subtracts one 40 bit binary number from another.
10. LSHF - Shifts a 40-bit binary number a given number of times to the left (lower memory location). Zeros are shifted into the emptied memory locations.
11. RSHF - Shifts a 40-bit binary number a given number of times to the right (higher memory location). Zeros are shifted into the emptied memory locations.
12. MULT - Multiplies one 40-bit binary number by another. Returns an 80-bit binary number as the answer.
13. ROTAT - The cordic rotation algorithm for determining trigonometric functions using a cordic table.
14. RECTPO - A rectangular to polar coordinate transformation (uses ROTAT).
15. POTREC - A polar to rectangular coordinate transformation (uses ROTAT). Can also be used to determine Sine and Cosine.
16. BCDTB2 - Converts a BCD number with 5 digits including two decimal places to a 40-bit binary number.
17. BCDTB4 - Converts a BCD number with 7 digits including 4 decimal places to a 40-bit binary number.
18. MOVB - Moves a 40-bit binary number from zero page memory to an absolute memory address location.

19. MOVA - Moves a 40-bit binary number from an absolute memory address location to zero page memory.
20. DIVIDE - Divides one 40-bit binary number by another.
21. DESEC - Provides a 1 second delay.
22. RSWITCH - Determines which coordinate is to be read from the coordinate thumbwheel digiswitches.
23. GETTUM - Stores the coordinate on the thumbwheel digiswitch at the proper memory address.
24. SETPT - Sets the pointers to the selected data origin site (tracker, site 1, or site 2).
25. PRTCOO - Prints the data origin coordinates entered on the front panel thumbwheel digiswitches when the "COOR" pushbutton is depressed.
26. NMI - Sets an identifying flag (number) only when in stop mode in a memory location after a non-maskable interrupt (NMI) is detected when the "HEADING" pushbutton is depressed. Refer to section 3.2.1 for further details.
27. IRQ - Sets an identifying flag (number) in a memory location after an interrupt request (IRQ) is detected when the "COOR" pushbutton is depressed. Refer to section 3.2.1 for further details.
28. TITLE - Prints the title when the "HEADING" pushbutton is depressed.
29. STATUS - Puts the status indicators on the output buffers.
30. MCONTR - Main control program as described in section 3.2.1.
31. INTCAL - Initial computation program as described in section 3.2.2.
32. MCOMPT - Main computation program as described in section 3.2.3.
33. RSITE - Computes the Azimuth angle and slant range between the tracker site and site 1.
34. TITL2 - Prints the tracker site to site 1 ground range and Azimuth angle.

3.3 Electrical Descriptions

The microcomputer electrical description is fairly simple compared to the software description. A block diagram of the microcomputer system is given in Figure 20. The Tradat V microcomputer system consists of the Microcomputer Card and the Program Card.

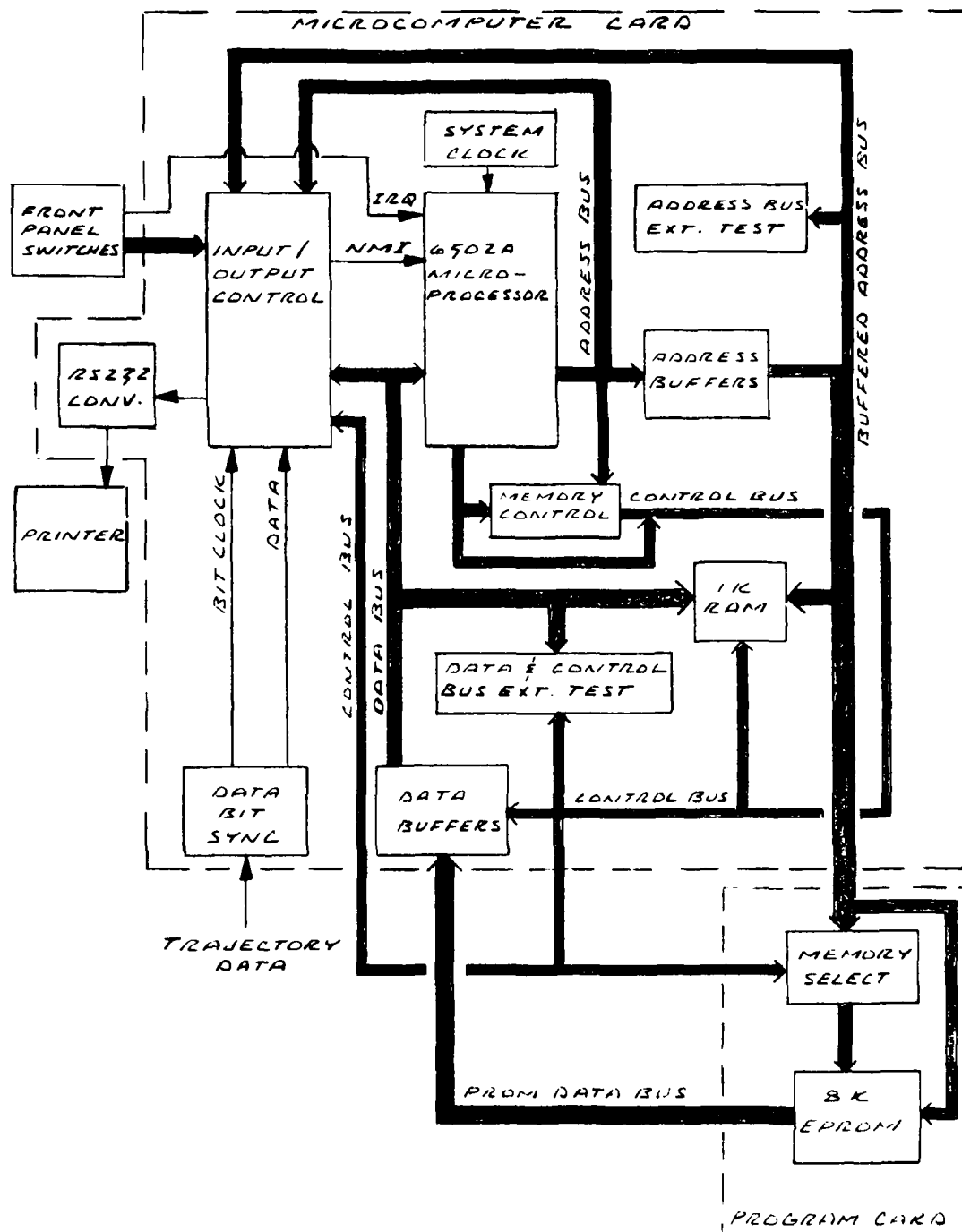


Figure 20. Tradat Microcomputer Block Diagram

3.3.1 Microcomputer Card (OSU Drawing D95GE04)

The microcomputer card (Figure 20) consists of the following functional blocks:

1. Data Bit Sync - The data bit sync (IC303 and IC310) conditions the trajectory data PCM code and reproduces a bit clock.
2. Input/Output Control - The coordinate thumbwheel digiswitch data is input through IC311-314. The "COOR" pushbutton is connected directly to the IRQ input on the microprocessor. The "HEADING" pushbutton is debounced through IC319 before entering the NMI input on the microprocessor. The coordinate select thumbwheel digiswitch, print rate, print format, and set pushbutton, and the conditioned trajectory data and bit clock are input to IC302, which is a R6522A versatile interface adapter. The input/output is controlled by the address bus and the control bus.
3. Microprocessor - The microprocessor is a MPS6502A, 2 MHz unit with the following inputs and outputs:

- 16 Address bus lines
- 8 Data bus lines
- RST - Reset
- NMI - Non-Maskable Interrupt
- IRQ - Interrupt Request
- R/W - Read/Write
- RDY - Ready
- 2 System Clock Lines
- +5 VDC Power
- Ground

4. System Clock - The system clock is a 2 MHz crystal oscillator circuit using IC317E and 317F.
5. Memory Control - The memory control circuit is used to construct the control bus which controls the input, output, RAM, or EPROM as the software requires during program operation. The 6502 microprocessor addresses inputs and outputs as if they were memory locations. IC315 uses address lines 13 through 15 to provide an 8K memory region select and IC316 uses address lines 10 through 12 to provide a 1K memory region select. IC's 321A, 321B, 321C, 317A, 317B, 317C, 317D, 318A, 318B, 318C, and 318D are used as control bus buffers and gates.
6. Address Buffers - The address lines are buffered by IC305, 306, and 307 to provide enough drive for the circuits that are addressed.
7. Data Buffers - The EPROM data lines are buffered and gate controlled by IC307 and 308.

8. 1K RAM - One kilobyte of random access memory is provided by IC303 and 304. The RAM is controlled by the control bus and the address lines, select the particular memory location as required by the software during program operation. The data bus accepts data from or data to the RAM as required by the software during program operation.

9. Data and Control Bus External Test - The data and Control busses are available on IC socket X324 for external testing.

10. Address Bus External Test - The address bus is available on connector X323 for external testing.

11. RS232 Converter - This unit consists of IC309 and converts the microcomputer TTL level outputs to RS232 outputs. The outputs consist of the output to the printer, an output monitor, and an auxiliary output.

3.3.2 Program Card (OSU Drawing D95GE04)

The Program Card (Figure 20) has sockets for 8 kilobytes of EPROM memory (IC501-508) but only 7 kilobytes are required for storing the Tradat V software. The only other circuit on the Program Card is the memory select circuit which consists of IC509. The memory select circuit uses address lines 10 through 12 and the R7 control line to select each 1 kilobyte of EPROM as required by the software during program operation. The address lines to each EPROM select the particular memory location required by the software during program operation.

3.4 Physical Description

The Tradat V microcomputer is included in the 5½" high rack-mount Tradat V console.

3.4.1 Chassis

The microcomputer part of the Tradat V chassis (Figure 8) consists of the Microcomputer Card and the Program Card. The Microcomputer Card is a double width (9") wire-wrap plug-in card and the Program Card is a single width (4.5") wire-wrap plug-in card. Both cards plug into the Tradat V card cage.

3.4.2 Front Panel

The microcomputer part of the Tradat V front panel is clearly marked as a functional section, as can be seen in Figure 9. The pushbutton switches are all indicator types with green indications except for those otherwise noted. The microcomputer front panel switches and sockets are as listed below:

- | | |
|---|--|
| 1. Coordinate thumbwheel digiswitches (9 switches) | For entering the latitude, longitude, and altitude of the data origin sites (tracker site, site 1, or site 2). The left digiswitch defines the coordinate, the next digiswitch defines the sign, and the remaining digiswitches enter the numerical value. |
| 2. "SET" momentary pushbutton switch. | For setting (entering) the coordinate displayed on the digiswitches into the microcomputer memory (must be in "STOP" mode). |
| 3. "STOP" (red) pushbutton switch. | Stops the output and allows coordinate data to be "SET". Interlocks with "DATA ORIGIN (RUN)" pushbuttons. |
| 4. "DATA ORIGIN (RUN)" interlocking switches (3 switches) | Selects the site from which the trajectory data will be referenced (tracker site, site 1, or site 2). Also, puts microcomputer in the "RUN" mode by interlocking with the "STOP" switch. |
| 5. "PRINTER" control switches | |
| a. Print Format
"GR/N/E" - "LAT/LONG" | Interlocking pushbutton switches to insert either the ground range, North, and East distances to the vehicle or the vehicle latitude & longitude into a line of output to the printer. |
| b. Print Rate
"1/sec-6/min-1/min" | Interlocking pushbutton switches to select a print rate of 1/sec, 6/min, or 1/min. |
| c. "DATA SOURCE"
"INT" (Grn) - "EXT" (Yel) | Interlocking pushbutton switches to select the raw trajectory data to the microcomputer input from either the Trajectory Data Coder Card in the internal mode, or an external source (such as a tape recorder playback) in the external mode. |
| 6. "INPUT" BNC Socket | The microcomputer input for raw trajectory data from an external source, such as a tape recorder playback when in the "EXT" mode. This input is resistance-isolated and parallel to the rear panel input. |
| 7. "OUTPUT" BNC Socket | The microcomputer RS232 output for monitoring or printing. This is isolated and parallel to the rear panel. |

3.4.3 Rear Panel

The microcomputer part of the Tradat V rear panel consists of only three BNC connectors as listed below:

1. "INPUT" BNC Jack

The microcomputer input for raw trajectory data from an external source such as a tape recorder playback when in the "EXT" mode. This input is resistance-isolated and parallel to the front panel input.

2. "BI-Ø OUTPUT" BNC Jack

An auxiliary microcomputer output.

3. "OUTPUT" BNC Jack

The microcomputer RS232 output to the printer. This is isolated and parallel to the front panel output.

4.0 TRADAT V SYSTEM SET-UP AND OPERATION

4.1 Installation

The Tradat V system should be installed adjacent to the controls for the tracker used in conjunction with Tradat V. The cabling should be done according to the cabling diagram in Figure 21. The multiconductor cables are labelled and all single line cables are RG-58 cables with BNC plugs except for the transmitter RF output cable which is a superflexible heliax cable with type "N" plugs. The video input should be from one receiver only and not from a selectable polarization diversity system.

The mounting arm should be bolted to the tracker and the helical transmitting antenna should be mounted to the mounting arm. An RG-8 cable should be used to connect the transmitting antenna to the tracking pedestal.

Install fan-fold paper in the printer. Verify that the printer ribbon is installed properly.

4.2 Preliminary Testing

After installation the Tradat V system can be tested in a "closed loop" fashion. The set-up procedure for testing the ranging part of the Tradat V console is as follows:

1. Turn off RF receiver used with Tradat V.
2. Turn on Tradat V console and allow a 10 minute warm up.
3. Cable range "CODE OUTPUT" to Range Decoder "CODE INPUT" on the front panel.
4. Select "VIDEO" position for Range Decoder Input Source push-button switch.
5. Turn on and start the time code generator.

The time code generator must be running for the ranging output and trajectory data coder to operate. The range on the front panel display should be stable and change as different offset adjust pushbuttons are selected. If this is the case, the Tradat V console ranging system is operating satisfactorily.

The trajectory data coder and microcomputer can also be tested using the following procedure:

1. Set up microcomputer described in section 4.3.
2. Select "STOP" mode.
3. Select "INT" data source mode.

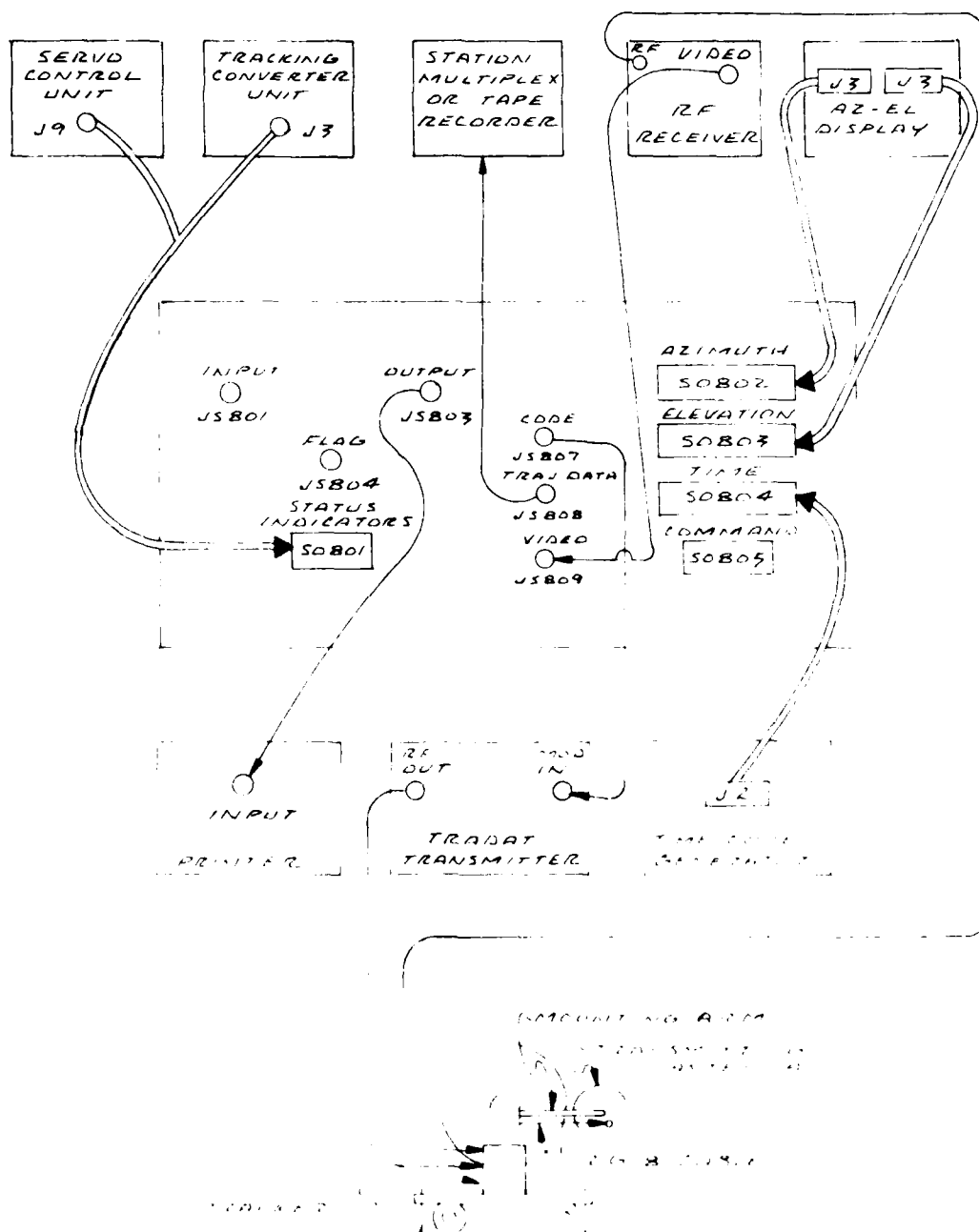


Figure 21. Tradat System Cabling Diagram

4. Select "CR/N/E" print format mode.
5. Select "1/sec" print rate.
6. Turn on printer.
7. Push "HEADING" pushbutton.
8. Verify a proper heading printout.
9. Verify that the coordinate part of the heading printout is accurate.
10. Select "TRACKER" DATA ORIGIN (RUN) mode.
11. Verify that a printout occurs once per second and that each printed item is correct.
12. Select "LAT/LONG" print format mode.
13. Verify that latitude and longitude are now printed out.
14. Push "COORD" pushbutton and verify that the proper coordinates are printed.
15. Select "6/MIN" print rate and verify proper print rate.
16. Select "1/MIN" print rate and verify proper print rate.
17. When preliminary testing is completed, remove the cable between the range "CODE OUTPUT" and the range decoder "CODE INPUT".
18. Turn RF receiver back on as required.
19. Verify that the "TRAJ DATA" output from the rear panel is being recorded properly through the station multiplex or directly on magnetic tape, whichever method is used. A channel 16 or higher SCO should be used if the trajectory data is multiplex recorded.

Verify proper operation of the ranging transmitter by turning it on and verifying that the low power level reads 2 watts and the high power level reads 50 watts and that the modulation is set at ± 150 KHz.

The time code generator/translator must be set on the exact Universal Time if used in the generate mode and must be locked onto the proper range time code if used in the translate mode. Use the time code generator/translator manual for initializing the time.

4.3 Microcomputer Initialization

The microcomputer must be initialized for every vehicle launch by entering the coordinates of the tracker site into the microcomputer. If the trajectory data is desired referenced to any other site such as a rocket launcher or another tracking site, the coordinates of up to two other sites (site 1 and site 2) must be entered into the microcomputer. These coordinates are entered into the microcomputer as follows:

1. Select "STOP" mode.
2. Select "TALT" (tracker altitude) on the left thumbwheel digi-switch.
3. Dial in the tracker altitude in Km on the remaining digiswitches using the correct sign (plus is altitude above sea level).
4. Push "SET" pushbutton to enter the tracker altitude.
5. Select "TLAT" (tracker latitude) on the left thumbwheel digi-switch.
6. Dial in the tracker latitude in degrees on the remaining digi-switches using the correct sign (plus is latitude in the northern hemisphere).
7. Push "SET" pushbutton to enter the tracker latitude.
8. Select "TLONG" (tracker longitude) on the left thumbwheel digi-switch.
9. Dial in the tracker longitude in degrees on the remaining digi-switches using the correct sign (plus is west longitude).
10. Push "SET" pushbutton to enter the tracker longitude.
11. Repeat steps 2 through 10 if required for site 1 coordinates and site 2 coordinates. If the vehicle is launched from a known launch site such as a rocket from a rocket launcher, site 1 should be used on the data origin for these coordinates so the distance and azimuth angle to the launcher can be computed and printed out with the heading for range initialization use.
12. Turn on printer.
13. Push "HEADING" pushbutton and verify that the coordinates were entered correctly.

If power is lost or if the Tradat V console is ever turned off, the coordinates must be re-entered. If no coordinates are entered, the data origin is assumed to be zero degrees latitude and longitude and zero Km altitude.

4.4 Airborne System

An FM/FM airborne ranging system is configured as shown in Figure 22. If the ranging receiver output is AC coupled, the subcarrier oscillator (SCO) should be set-up for plus and minus 2.5v operation. If the receiver output is DC coupled, the SCO should be set-up for zero to 5v operation. The receiver output should be set so that its output remains within the 5v limitation with ranging output or with noise on the output. If the receiver remains within the 5v limitation, squelch on the ranging receiver is not necessary. If the

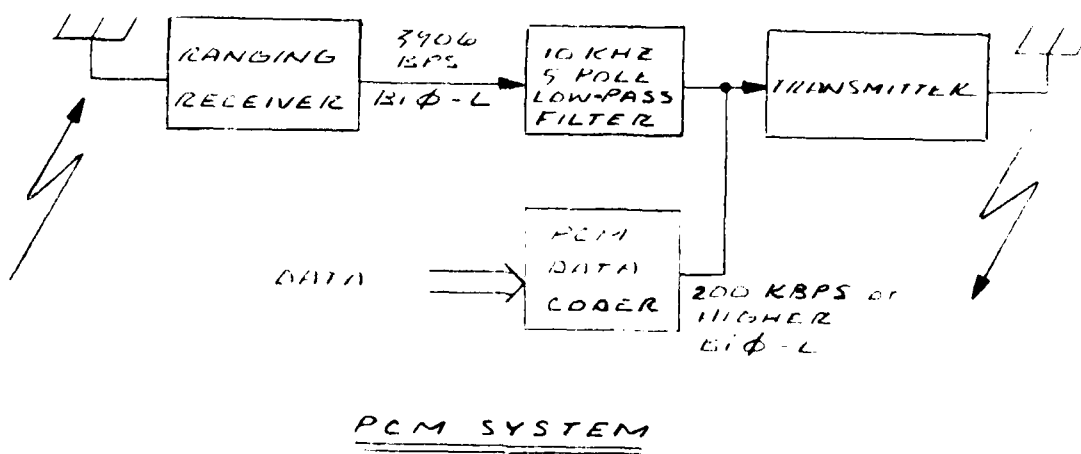
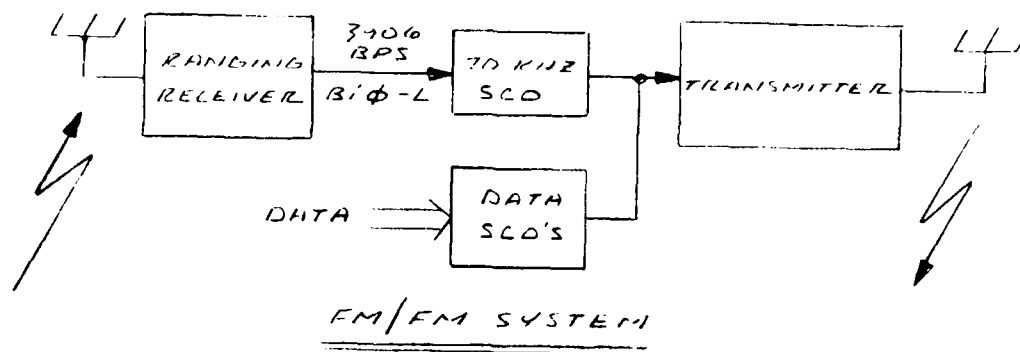


Figure 22. Airborne Ranging System

receiver output exceeds the 5v limitation, the ranging SCO will be driven out of band and affect adjacent data SCO's.

A PCM airborne ranging system is configured as also shown in Figure 22. The output of the ranging receiver is filtered before being mixed with the PCM data stream. If the noise output of the receiver is at or below that of the data level, squelch is not necessary on the ranging receiver. The receiver output is adjusted to occupy approximately 20% of the bandwidth when mixed with the PCM data code. The Biphase-Level PCM data code can be less than 200 KBPS but with increasingly more affect on the ranging accuracy. For using Tradat V with low bit rate PCM data systems, the PCM data code can be used to modulate a high frequency SCO and the ranging system can be used in the FM/FM mode.

4.5 Range Initialization

The Tradat V system was designed to be used with different telemetry systems. This necessitated the need to adjust or initialize the range for use with each particular telemetry system. The Tradat V system should be initialized as follows:

1. Complete the procedures listed in sections 4.1 - 4.4.
2. Operate airborne system a known distance away.
3. Turn on the Tradat V system and time code generator and allow a 10 minute warm-up.
4. Turn on the ranging transmitter.
5. Acquire and autotrack the vehicle with the tracker.
6. Select the proper RANGE decoder input source. ("DISC" for FM/FM systems, "VIDEO" for PCM systems.)
7. Adjust the selected input source level to between .5v and 10v peak to peak. (The discriminator output should be adjusted when using FM/FM telemetry systems, and the RF receiver video level should be adjusted when using PCM telemetry systems.)
8. Use the "OFFSET ADJUST" pushbutton switches to change the range readout until it is within .15 Km of the distance in Km from the tracker to the vehicle. This distance is the printed value on the heading if the vehicle is located at Site 1. Use the "FINE" adjust to make the range readout equal the distance. After the range has been initialized, no changes should be made in any of the telemetry system adjustments such as IF filter, video level, video filter, etc.

9. The "FINE" adjust can be used to make any last minute adjustments just prior to launch.

4.6 Operation

No adjustments are required on the Tradat V system during operation, but the following steps should be followed just prior to vehicle launch:

1. Verify that the procedures in sections 4.1 - 4.5 have been completed.
2. Verify that the time code generator is locked to the proper time.
3. Turn on Tradat V system including the ranging transmitter and allow a 10 minute warm-up.
4. Select the microcomputer "STOP" mode.
5. Select the "INT" trajectory data source mode.
6. Verify that enough fan-fold paper is loaded into the printer.
7. Set the top of form printer adjustment by feeding the paper until it is 3 spaces beyond the fanfold crease and depressing the "TOP OF FORM SET" (TOF). This causes the printer to automatically skip over the creases.
8. Push the "HEADING" pushbutton to print the heading.
9. Select the print format desired ("GR/N/E" or "LAT/LONG").
10. Select the print rate desired ("1/SEC", "6/MIN", or "1/MIN").
11. Approximately 30 seconds before launch select the DATA ORIGIN (RUN) pushbutton desired (Tracker, Site 1, or Site 2). The trajectory data will now automatically be printed throughout the flight.

5.0 COMMAND THROUGH RANGING OPTION

The Tradat V trajectory system can be used to provide commands to an airborne vehicle while simultaneously providing ranging data. The command capability can be added to Tradat by simply cabling in the optional command console. Only one multiconductor cable and two RG-58 cables are required. Figures 23 and 24 are the front and rear views of the 3½" rack height command console.

The system is very flexible and can easily be modified to suit differing command requirements. The basic version consists of 32 independent, secure, one-bit commands. Any number of commands can be given simultaneously and every command is secure against being triggered by a noisy command RF link.

The PCM uplink command/ranging code consists of four sixteen-bit minor frames of which the first eight bits are reserved for the frame sync. The last 8 bits of the four subframes provide the 32 bit command capability. The airborne command decoder prevents a noisy signal from generating a false command by requiring the perfect reception of 16 minor frames before the command output is enabled. A unique feature of the airborne command system is that the PCM downlink command/ranging code is reconstructed such that the command bits are replaced by command confirmation bits. The command confirmation code verifies that the airborne command system actually received and gave any particular command to the airborne unit that was to receive the command. The command confirmation system could be modified to indicate that the commanded unit was actuated. In other words, the return command/ranging code can be used as an independent telemetry data code. The LED indicators above the command switches on the command console are the command confirmation indicators. These lights confirm that the command was actually received not that it was just transmitted. The LED indicator in the center of the panel indicates a loss of lock on the received PCM command confirmation code. Use of the command confirmation while ranging will cause small shifts in the range when commands are given. These shifts in range are normally well within 100 Km. These range shifts are minimized by blanking the command portion of the code before it enters the Tradat V console.

The system can be modified to provide more than 32 commands by increasing the number of subframes. Each additional subframe would provide 8 additional commands.

There are several methods of providing even greater security against giving false commands. One bit could be used to initialize a command and another bit

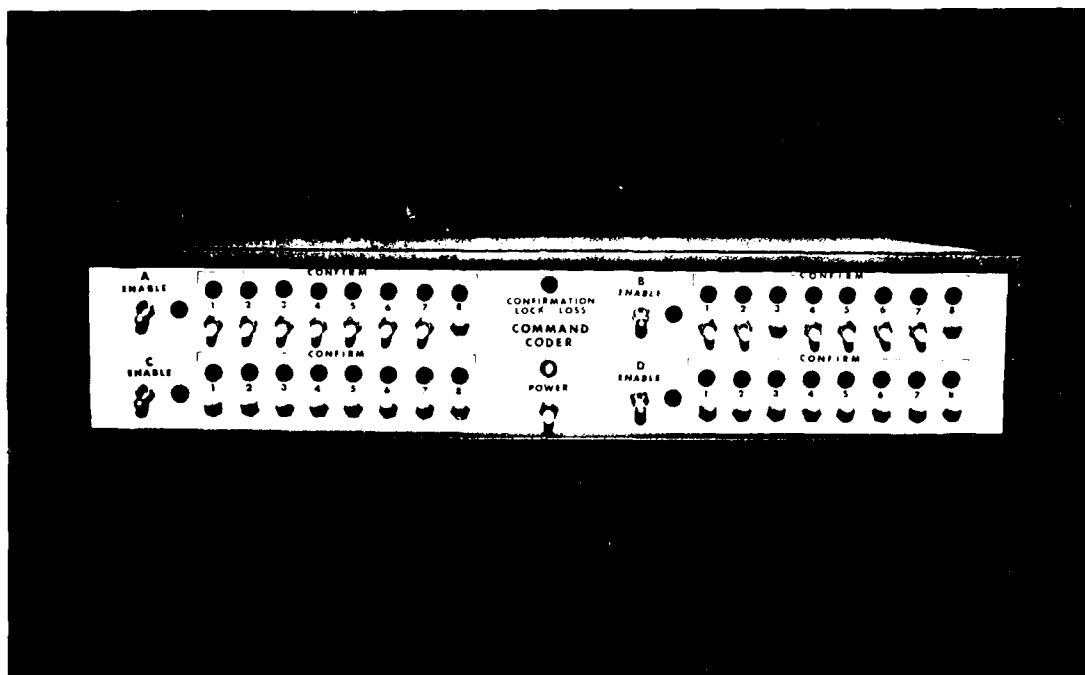


Figure 23. Command Console Front Panel

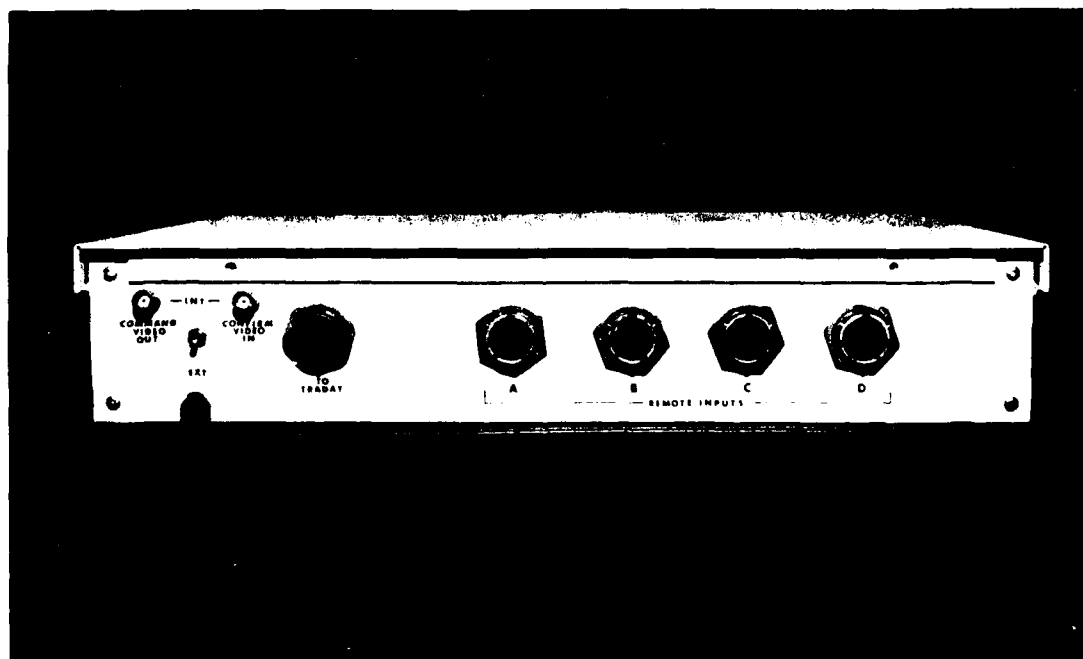


Figure 24. Command Console Rear Panel

could be used to actuate the command. Another method would be to use several bits in a pattern to activate a command.

Commands may be given from the front panel using the toggle switches (Figure 23) or they may be given from a remote command device connected to the command console rear panel (Figure 24). Each block of eight commands can be enabled or disabled with a locking type toggle switch. An LED display illuminates to indicate that a particular command block is enabled.

The command console can be operated as a stand alone system without the Tradat V console if ranging is not required. Of course, the uplink transmitter is still required. A rear panel toggle switch is used to select whether the command system is used with or without Tradat V.

5.1 Command Console

The command console is a $3\frac{1}{2}$ " high rack mount unit. It consists of the command coder and the command confirmation decoder.

5.1.1 Command Coder

The command coder (Figure 25) consists of four 8-bit parallel to serial shift registers. These shift registers receive their bit clock and parallel enter pulses (minor frame sync) from Tradat V. The bit clock and parallel enter pulses are available at buffered outputs for any remote command device. The parallel data to these shift registers consists of the data selected by the front panel command switches. The output of each shift register and the output from each remote command device are "OR" gated to a multiplexer which receives its multiplex control from the ranging coder in Tradat. The multiplexed command output is buffered and fed to the ranging code in Tradat to make up the last 8-bits of each minor frame.

The command console has a built in ranging code generator and sync detector similar to the one in the Tradat console. It is used in place of the Tradat system when the rear panel toggle switch is placed in the "INT" mode. This allows the system to be tested independently from the Tradat system by cabling the rear panel "Command Video Out" to the "Confirm Video In". This also allows the command system to be used operationally without the Tradat system. The "Command Video Out" is used to modulate the uplink command transmitter and the received confirmation PCM code is fed to the "Confirm Video In".

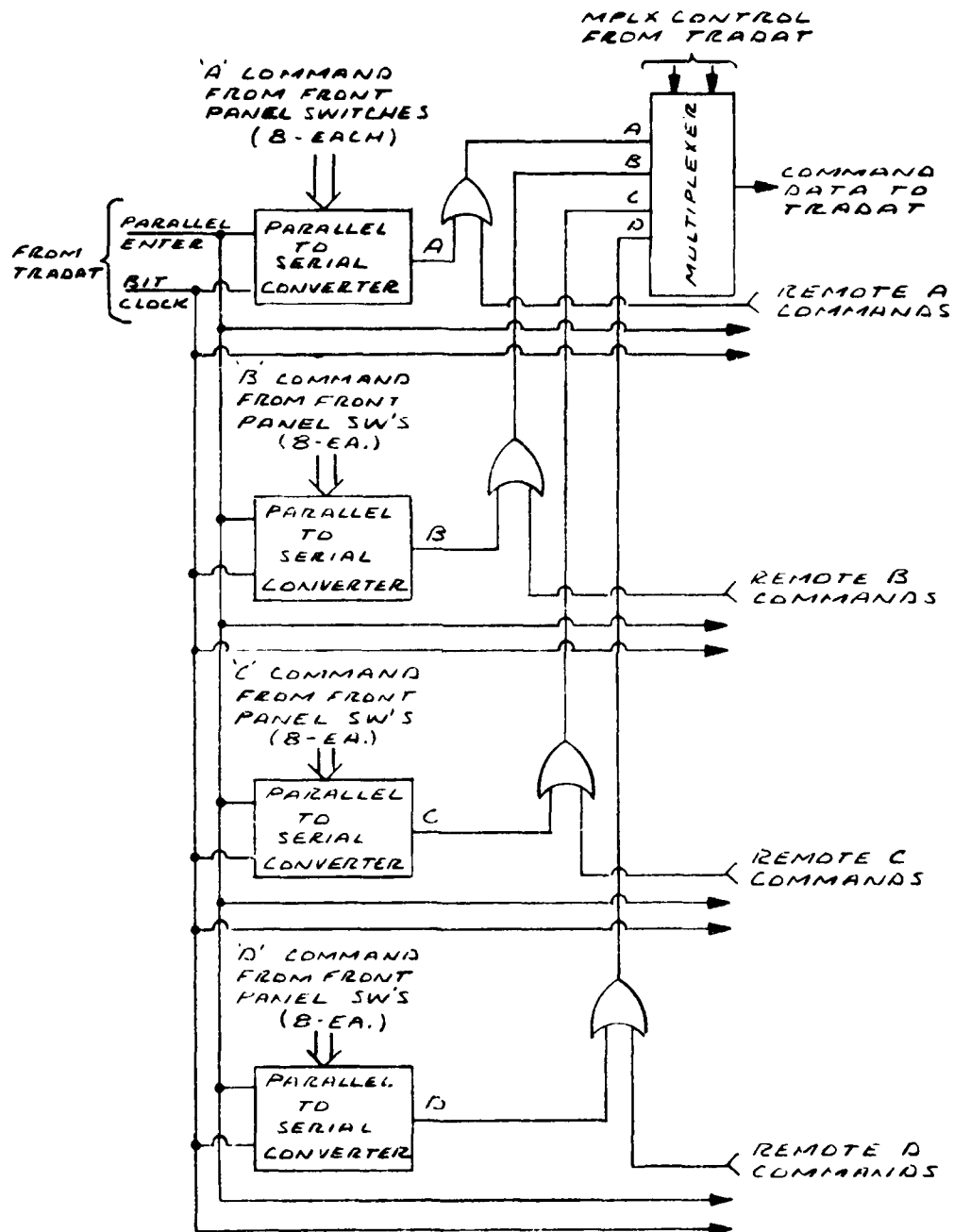


Figure 25. Command Coder

5.1.2 Command Confirmation Decoder

The PCM command/ranging code and bit clock from the ranging sync detector in Tradat V are entered into the command confirmation decoder (Figure 26). This is the code that has been reconstructed in the airborne decoder to provide command confirmation data. The code is clocked into four eight-bit shift and store bus registers by the bit clock. The confirm latch control from the ranging sync detector is demultiplexed and the demultiplexed outputs are used as latches to the shift register. The parallel confirmation outputs from the shift registers are buffered to drive the front panel LED confirmation indicators.

The confirmation data, bit clock, and demultiplexed latches are available on the rear panel connectors to the remote command devices. This allows command confirmation indicators to operate on the remote command devices.

5.2 Airborne Command Decoder

The airborne command decoder (Figure 27) provides security against false commands, decodes command data, and formats the command confirmation data for transmission to the ground system. A typical airborne decoder schematic is an OSI drawing C40PD01. This particular decoder was designed to decode only 16 commands.

The command data from the airborne receiver is conditioned by IC306D. The bit clock is reproduced using IC306C to produce positive pulses at each code transition and using these pulses to drive a one-shot clock (IC308B). The Biphasic-L input code is converted to NRZ-L in IC307A. The inverted major frame of the conditioned data is reinverted by IC307B and 306A to produce all non-inverted data. The PCM frame sync code is converted to parallel form by IC310 and 312 and fed into the sync detector. The minor frame sync is detected by IC302, 313, 314, and 316C. The minor frame sync is input to the minor frame clock and the minor frame gate. The major frame sync is detected by using the minor frame sync and the major frame indication bit in IC309A, 316B, and 316D. The major frame sync is used in the major frame inverter on the input and output sections of the decoder.

The NRZ-L command data is delayed 64 bits (one major frame) in IC311 and compared with the next 64 bits on a bit by bit basis in IC306B. If any bit comparison fails, the minor frame counter (IC317) is reset and the command output is disabled. The minor frame counter must count 16 minor frames (256 bits) before the command is enabled. The minor frame sync gate is disabled when 16 minor frames are counted so that the counter output will not disable the

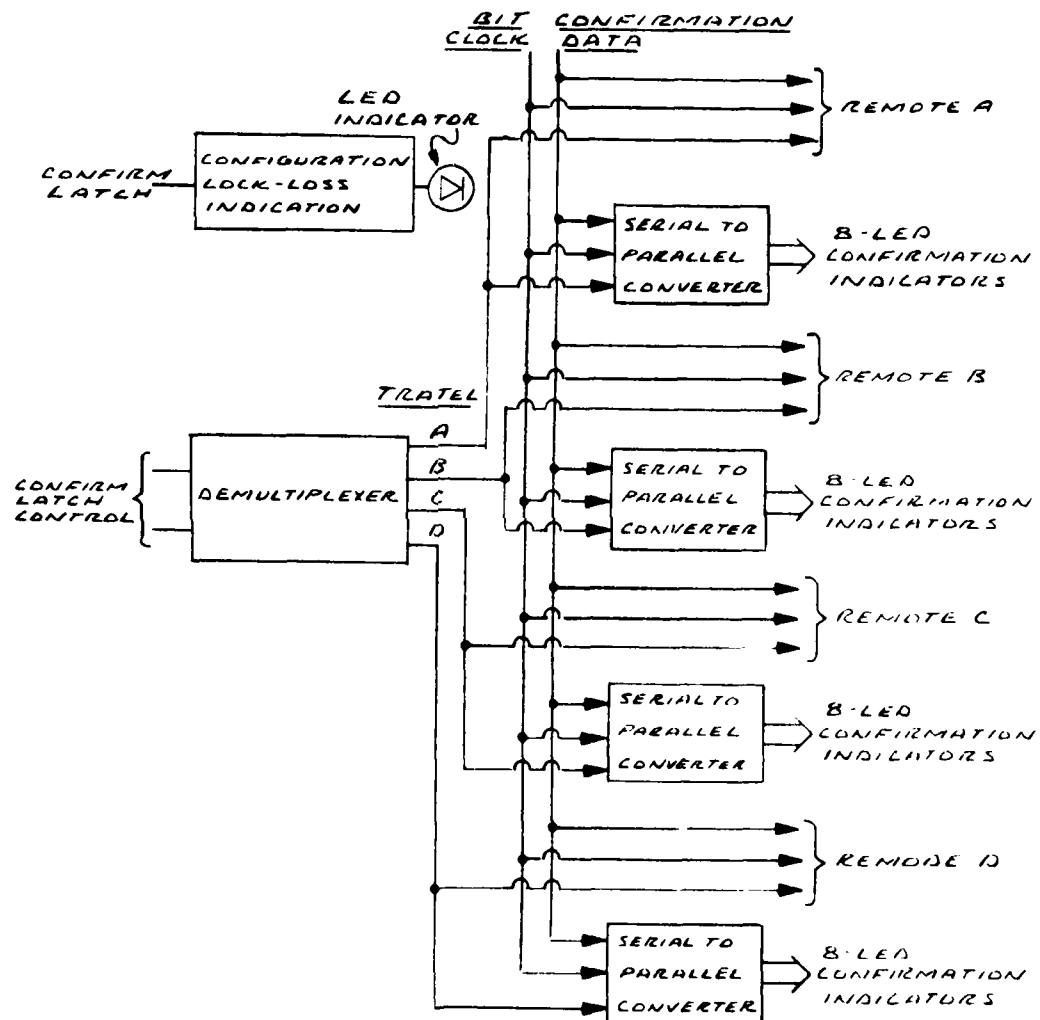


Figure 26. Command Confirmation Decoder

command output after the next 16 minor frames are counted.

The NRZ-L command data is clocked into a serial to parallel shift register (IC318 and 324). Each block of 8 command bits has its own shift register. Each shift register must have an enable signal from the minor frame counter and the proper signal from the word demultiplexer (IC305A) before a command will be present on the output of the shift register. The word demultiplexer receives the input from a circuit (IC315) that delays the minor frame sync so that data has enough time to enter the serial-to-parallel shift register before it is clocked out. The delay circuit is reset by the minor frame counter so that the clock pulses are available to the word demultiplexer only between the eighth and sixteenth minor frame counts. An RC circuit on each command output of the shift registers holds any command bit for about one second after it has been removed to prevent any momentary command dropouts caused by uplink RF noise or any new commands that would momentarily disable the shift register. The command data on the output of the shift register is buffered by IC319, 320, and 325 and fed into high voltage, high current drivers (IC322, 323, and 327). Other command interface techniques may be used depending on the particular application.

The received command data is reformatted by replacing the uplink command data with the commands that are on the command decoder output buffers. These reformatted command words are called the command confirmation data. The parallel command data from the buffers is clocked into the parallel-to-serial converter (IC321 and 326) by the data enter clock from the word clock (IC309B). The word clock receives its input from the bit clock shaper (IC308A) and is reset by the minor frame sync. The word clock counts 8 bits and is reset every 16 bits to provide an 8-bit word clock. The four 8-bit command words are multiplexed by IC305B which receives its word numbers from IC309A in the sync detector. The confirmation data is converted to a Biphase-Level code in IC304B and inverted every other major frame in IC304A to reproduce the inverted input data format. The verification data is gated by the word clock in IC303A and combined with the frame sync word in the code combiner (IC304C). The command word on each minor frame of the input PCM code is blanked out by the frame sync gate (IC303A) before the frame sync word is combined with the command confirmation word.

The reconstructed confirmation PCM code is filtered in a 5-pole lowpass premodulation filter. The filtered code is mixed with the PCM data in PCM telemetry systems or used to modulate a 70 KHz SCO in FM/FM telemetry systems.

6.0 RESULTS AND CONCLUSIONS

The Tradat V system has been used on one rocket launch mission (rocket number A18.805) at White Sands Missile Range, New Mexico, and two balloon launch missions (Project BAMB), one at Holloman AFB, New Mexico, and one at Keesler AFB, Miss. A Tradat V prototype system was used with several rockets during the 1979 Red Lake, Ontario, Canada, Solar Eclipse expedition. Although radar data is not yet available for exact comparisons, quick look comparisons are very favorable between Tradat V and radar data. NASA Wallops Flight Center has ordered four Tradat V systems and have tested the first system on a rocket flight. Preliminary results show favorable comparisons between the Tradat V and radar data.

The advantages of the Tradat V system are as follows:

1. Relatively small and lightweight.
2. Relatively inexpensive.
3. Negates the need for radar sets at remote launch sites.
4. Accurate enough for most applications ($\pm .05$ Km RMS).
5. Easy to set up and operate.
6. Provides quick look microcomputer trajectory output for vehicle recovery, preliminary data analysis, and vehicle performance analysis.
7. Can be used to make trajectory data playbacks at the launch site for use by interested persons.
8. Easily integrated with existing telemetry trackers to provide ranging.
9. Can be used with command option to provide secure commands to airborne systems.

During the balloon launch missions the microcomputer development system was used in addition to the Tradat V microcomputer to provide balloon navigation data and instrument target data. These computations were done in Basic Language. The navigation printout (Figure 28) included the balloon horizontal velocity and heading and ascent rate, in addition to the other Tradat position data. Another program could be called up on an interrupt basis to be used to compute information regarding either a ground target or aircraft target for the balloon-borne instruments. The ground target program involved entering anticipated target data so that the microcomputer would compute the anticipated

GR (NM)= 2.96 GR (SM)= 3.4 AZ (DEG)= 287.75
 GR (KM)= 5.48 N (KM)= 1.67 E (KM)= 5.22
 H.VEL. (KTS)= .36 H.VEL. (MPH)= .01 HEADING= 107.21
 MSL ALT (FT)= 27225.62 ASC. RATE (FT/MIN)= -54.76
 B LAT= 30 DEG 25.11 MIN B LONG= 88 DEG 58.64 MIN

EL, AZ, SR, TIME, F1, F2, F3? +056.55, +287.75, +009.95, 01, 03, 30, 0, 0, 0

TIME= 1 : 3 : 30 DATA SOURCE: OSU
 GR (NM)= 2.96 GR (SM)= 3.4 AZ (DEG)= 287.75
 GR (KM)= 5.48 N (KM)= 1.67 E (KM)= 5.22
 H.VEL. (KTS)= 0 H.VEL. (MPH)= 0 HEADING= 0
 MSL ALT (FT)= 27225.62 ASC. RATE (FT/MIN)= -.01
 B LAT= 30 DEG 25.11 MIN B LONG= 88 DEG 58.64 MIN

EL, AZ, SR, TIME, F1, F2, F3? +056.55, +287.75, +009.94, 01, 03, 40, 1, 0, 0

GROUND OR AIRCRAFT?? AIRCRAFT
 PREDICTED TARGET TIME (HH, MM, SS)? 10, 10, 40
 TARGET AZ? 235
 TARGET EL? 13
 TARGET ALTITUDE (FT)? 0

PRED. TIME= 10 : 10 : 40 DATA SOURCE: OSU
 PRED. NORTH (KM)= 1.67 PRED. EAST (KM)= 1.67
 PRED. GR (NM)= 2.96 PRED. GR (SM)= 3.4 PRED. AZ= 287.73
 PRED. MSL ALT. (FT)= 27220.15
 PRED. LAT= 30 DEG 25.11 MIN
 LONG= 88 DEG 25.11 MIN
 PRED. AIRCRAFT LAT= 30 DEG 25.11 MIN
 LONG= 88 DEG 58.64 MIN

EL, AZ, SR, TIME, F1, F2, F3? +056.55, +287.75, +009.94, 01, 04, 20, 0, 0, 0

TIME= 1 : 4 : 20 DATA SOURCE: OSU
 GR (NM)= 2.95 GR (SM)= 3.4 AZ (DEG)= 287.75
 GR (KM)= 5.47 N (KM)= 1.67 E (KM)= 5.21
 H.VEL. (KTS)= .21 H.VEL. (MPH)= .20 HEADING= 107.21
 MSL ALT (FT)= 27198.24 ASC. RATE (FT/MIN)= -32.65
 B LAT= 30 DEG 25.11 MIN B LONG= 88 DEG 58.63 MIN

EL, AZ, SR, TIME, F1, F2, F3? +056.55, +287.75, +009.94, 01, 04, 30, 1, 0, 0

GROUND OR AIRCRAFT?? GROUND
 PREDICTED TARGET TIME (HH, MM, SS)? 10, 10, 30
 TARGET LATITUDE (DD, MM, SS)? 30, 30, 0
 TARGET LONGITUDE (DDD, MM, SS)? 88, 50, 0
 TARGET ALTITUDE (FT)? 100

PRED. TIME= 10 : 10 : 30 DATA SOURCE: OSU
 PRED. NORTH (KM)= .57 PRED. EAST (KM)= .57
 PRED. GR (NM)= 1.01 PRED. GR (SM)= 1.01 PRED. AZ= 287.73
 PRED. MSL ALT. (FT)= 9256.66
 PRED. LAT= 30 DEG 24.52 MIN
 LONG= 88 DEG 24.52 MIN
 TARGET AZ (DEG)= 13.61 TARGET EL (DEG)= 23.13

Figure 28. Balloon Navigation Data

balloon position and instrument pointing angle. The aircraft target program involved entering the anticipated aircraft altitude, instrument data taking time, and instrument pointing angles and the microcomputer would compute the latitude and longitude that the aircraft had to fly through at the data taking time.

Another Basic Language program was developed on the microcomputer development system to compute North Star position data for use in setting up the tracker.

Future work on the Tradat V system could consist of:

1. Adding a smoothing algorithm in the microcomputer software.
2. Developing an add-on microcomputer for calculating wind velocities and/or meteorological data by tracking and ranging on a balloon-sonde or rocket sonde.
3. Modifying the software to compute other parameters such as the navigation program described previously.

The small size and programmability of dedicated (special purpose) microcomputers make them ideally suited for sounding rocket and balloon mission support, since these missions are very diverse and are undertaken at launch sites all over the world. Microcomputers are very versatile and can perform a broad spectrum of tasks from dedicated control to data processing and can be used in place of many types of equipment from hard-wired digital logic to large computers. Microcomputers may be used to replace hard-wired digital logic in airborne PCM coders and ground station PCM decoders. They may also be used to replace computers in such applications as the Tradat V trajectory data system and real time conversion of telemetry data into engineering units. The ability of microcomputers to control various telemetry data display devices makes them useful in making quick prelaunch instrument readiness decisions. Proper implementation of microcomputers will allow the use of increasingly more complex instruments in sounding rockets and balloon missions.

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